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## **Photovoltaic Energy in Kuwait: A Financial and Environmental Analysis**

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# Photovoltaic Energy in Kuwait: A Financial and Environmental Analysis

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A thesis submitted for the degree of Doctor of Philosophy

**University of Bath**

Department of Mechanical Engineering

June 2017

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## SUMMARY

This research is concerned with the drivers to utilize Renewable Energy in Gulf Cooperation Council countries with a focus on Kuwait. Such countries show high rates of electricity subsidies with high rate of emissions. At present, there is a continuous need to build new power stations to increase the electrical capacities, in order to cover the high peak loads that occurs in summers to avoid blackouts.

The aim of this research is to create a combination of approaches to assess the adoption (economic and environmental) of Photovoltaic for electricity generation in Kuwait, which can be used to assist policy makers to compare various energy mixes and hence determine whether their current and future strategies are appropriate.

Kuwait is in this research representative of an exemplar of oil-based economy in Gulf Cooperation Council region since they share similar energy policies and geographic location. The research provides an insight into the adoption of renewables in the region and the impact that particular energy mixes may have.

Nine future potential scenarios are created showing different levels of PV deployment within Kuwait. The combination of approaches in this research estimates the economic and environmental impacts using Levelized Cost of Electricity and Life Cycle Assessment respectively of differing RE mixes.

The findings show that energy storage increases the cost of electricity and the emissions from the photovoltaic sector. However, for the energy mix (PV and conventional), assuming oil price greater than 10.1\$/Bbl. (when no storage required) and 15.2\$/Bbl. (when using storage), PV generally lowers the cost of electricity, CO<sub>2</sub> and SO<sub>2</sub> emissions. Whilst, human toxicity is increased when storage is used. Taking all these factors into account, PV deployment is generally beneficial. However, if different combinations of impacts are considered, environmental and economic impacts may take different patterns. This led to a multi-objective problem to be solved. Using Pareto Front analysis, scenarios without storage requirement (i.e. 13% or less of photovoltaic) are preferable if only cost and human toxicity are considered.

The contribution to knowledge from this research is that the deployment of large scale PV technology is beneficial in Kuwait economically and environmentally at least until 30% of

the maximum peak load of electricity. The results have implications for other GCC countries with similar geographical, political and energy drivers; the methodology used in this research would be appropriate for these contexts.

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## ABBREVIATIONS

CO <sub>2</sub>	Carbon dioxide
COP	Conference of the Parties
CSP	Concentrated Solar power
DB	Dichlorobenzene
DNI	Direct Normal Irradiance
GCC	Gulf Cooperation Council
GHG	Greenhouse Gas
GW	Giga Watts
GWh	Giga Watts hours
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kg	Kilograms
KWD	Kuwaiti Dinar
KSA	Kingdom of Saudi Arabia
kW	Kilo Watts
kWh	Kilo Watts hours
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Electricity
MW	Mega Watts
MWh	Mega Watts hours
MWp	Mega Watts peak
OPEC	Organization of the Petroleum Exporting Countries
PV	Photovoltaic

RE	Renewable Energy
RET	Renewable Energy Technology
SO <sub>2</sub>	Sulfur dioxide
TWh	Tera Watts hours
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars

## **1. INTRODUCTION**

Renewable energies (RE) reduce the impacts of emission from the electricity generation sectors (Ferroukhi et al., 2016; Sawin, 2013). Globally, energy generation is heavily reliant on fossil fuels, oil and coal; with their resulting environmental pollution, as well as being these sources which are not sustainable. With the increasing global population and energy need, using alternative sources of energy generation to support conventional sources is required. Renewable Energies are a potential option (IRENA, 2016b).

The adoption of RE and their implementations in different parts of the globe are influenced by a diverse number of factors. Besides the pressure posed by the unsustainable (resource depletion) nature of conventional energy sources and the global population increase, economic factors play a critical role in the adoption of RE. RE has been proven to be a viable and often seen as a less costly source of energy generation compared with conventional energy production methods (Lazard, 2015). This is especially important in areas where fossil fuels such as coal and oil are not naturally found, i.e. imported (IRENA, 2016b). The economic drivers can be quantified by considering the cost implications of adopting RE relative to conventional power plants. These implications also include the employment opportunities that RE creates in different economies. When oil based power plants are used, the use of RE will increase oil exports and improve country's economy.

On the political front, the main drivers include the political obligations demonstrated by different countries. In the recent past, it has been universally agreed that there is a need to reduce emissions to curb environmental degradation and reduce social burdens associated with pollutants from conventional power plants. Such commitments are captured in a number of agreements and protocols agreed at international conferences. An example is the Kyoto Protocols of the United Nations Framework Convention on Climate Change (UNFCCC) which captures the climate agreement between member countries commitment to lower their carbon footprint (United Nations, 2012). Other meetings conducted to cement the global commitment toward a healthy environment include the Conference of the Parties (COP) 21 and COP22 held in Paris and Marrakesh respectively (UN\_FCCC, 2015; UNFCCC, 2016). However, although there is a push towards RE, countries such as those in the Gulf Cooperation Council (GCC) region gain their wealth mainly through oil. This can make the move to RE more challenging.

## **1.1 The Gulf Cooperation Council region**

The Gulf Cooperation Council (GCC) is an alliance made up of six member countries of the world's largest oil producer and was founded in 1981. These countries are Kuwait, Saudi Arabia, United Arab Emirates (UAE), Oman, Bahrain and Qatar. According to Organization of the Petroleum Exporting Countries (OPEC), the GCC is home to approximately a third of the world's proven oil reserves (OPEC, 2016).

The GCC countries have numerous similarities not just oil and gas production. Politically, these countries have a similar environment (Naufal & Genc, 2014). Geographically, the countries are located in the Middle East and border each other. Their climatic conditions are characterised by high temperatures during summer (Arab Sustainability Association, 2013).

Despite the recent approaches toward diversifying their economies, the GCC countries are still reliant on returns from export of oil and gas (Ulrichsen, 2016). Proceeds from exports of oil and gas are the main contributor to their economies, with the benefits gained from the oil wealth including infrastructure through to health, education and social amenities provision. This wealth has also enabled the governments to subsidise electricity despite the high demand in the region (Abdmouleh, et al., 2015; Ameer & Krarti, 2016).

Unlike many other countries, GCC countries, production of energy for electricity is mainly reliant on conventional power production methods, i.e. through the use of fossil fuels (Abdmouleh, et al., 2015; Gelil, 2015). The growing population in the GCC region is increasing the demand for electricity which has led to the expansion of the energy production sector to avoid blackouts occurring during periods of peak electricity demand.

As GCC countries produce approximately 23.6% of the world's oil, utilising RE in GCC countries energy mix would mean extra oil and gas for export, thus, promoting their economies (IRENA, 2016b). It also has the potential to decrease energy cost in GCC countries enabling the region to continue with its energy policy of offering high subsidies on electricity, whilst achieving lower cost to the GCC governments. Adoption of RE would also mean extra job opportunities for the citizens of the GCC region. According to IRENA (2016b), approximately 210,000 jobs could be created if all the GCC targets were achieved by 2030. In this research one of the GCC countries is investigated, namely Kuwait.

## 1.2 Kuwait

Kuwait is a GCC member country covering 17, 818 sq. kilometres of land. It borders Iraq and Saudi Arabia. The country is noted to have a growing population. Currently the population is 4 million (Population Reference Bureau, 2016) with an annual growth rate of approximately 3.9% expected (Stiftung, 2014). Kuwait experiences a desert climate with high temperatures characterized by long, hot dry summers ( $\sim 45^{\circ}\text{C}$ ) with a high number of sunny days (140 days) and warm short winters with occasional rainfalls (Bou-Rabee, et al., 2017).

Economically, Kuwait is an open economy country endowed with crude oil proven reserves of approximately 101.5 billion barrels. This equates to Kuwait being ninth globally in terms of oil reserves (IRENA, 2016b). Its economy is mainly dependent on oil and oil products exports and has a large public sector compared to the private sectors. In terms of economic diversification, unlike other GCC countries such as UAE that have invested in Tourism, Kuwait has little diversification. This is, to some extent credited to having a small private sector, an unfavourable business environment and government policies that are seen as hindrances. These policies hamper market entry and are not conducive for credit accessibility (Hertog, 2013; IEA, 2016)

Kuwait is the focus of the research presented in this thesis and as a country it has distinctive characteristics beyond the rest of the GCC countries. The first difference is that Kuwait has the least amount of RE projects (0.2MW) relative to other GCC countries (IRENA, 2016a). One of the initial findings of the literature was that there is a lack of results based on experiments to quantify RE impacts for Kuwait.

Moreover, it has the highest cost of electricity production among GCC countries at \$ 13.1 cent/kWh (Abdmouleh, et al., 2015) and at the same time it has the lowest electricity tariff in GCC countries (2fils/kWh or approximately \$ 0.7 cent/kWh (Fattouh & Mahadeva, 2014; IRENA, 2016b). This means Kuwait is expected to be one of the most beneficial GCC countries for decreasing the cost of electricity. Noting the high annual increase in electricity demand (7% per year) in Kuwait (Ferroukhi, et al., 2016), more power plants need to be established on a regular basis to avoid blackouts.

Another reason that makes Kuwait a viable target for this research is its commitment toward reducing Green House Gas (GHG) emissions. This is evidence by the government's action of ratifying the UNFCCC agreements in 1995 followed by the Kyoto Protocol in 2005 (Environment Public Authority Kuwait, 2012). In 2015 the State of Kuwait affirmed its staunch position regarding environmental sustainability by submitting its new climate

action plan that would guide it until 2035 at the UNFCCC convention in Paris, (The State of Kuwait, 2015). Kuwait also committed to the COP22 in Marrakesh in 2016 (United Nations, 2016)

Of the options available for renewable energy, photovoltaic (PV) is a RE technology being used to convert solar power directly to electricity (Covert et al., 2016; Chung et al., 2015). PV has been the subject of a number of studies and has been identified as one of the main RE technologies (Bhandari et al., 2015; Khalid & Junaidi, 2012.; Pickrell et al., 2013) with developments in PV panels continually innovating. The price per watt has decreased from 4.9\$ to 1.5\$ from 2009 to 2016, and the efficiency has increased from 16% to 22%. This trend is expected to continue beyond 2025 (IRENA, 2016).

### **1.3 Scope of Research**

Current research aimed at assessing such technologies has tended to focus on Europe (Norway, Spain, Germany, Italy and France, Austria among others) with limited cross-country analysis being undertaken (EU, 2014). Various factors can affect the viability and importance of PV in any given country (Norberto et al., 2016). Those factors range from the abundance and price of traditional fossil fuel energy sources, to the irradiation that falls on the lands of this region (Bridle & Kitson, 2014) as well as the regional and local laws and regulations that may or may not assist in the widespread adoption of PV (NRG Magazine, 2014). Despite Kuwait having factors that are positive for adopting PV, such as high fossil fuel prices, high irradiation rates in the Kuwaiti geographic area and regulations shifting to RE, there is a lack of studies on the impact of adopting PV in Kuwait. In particular there is a lack of studies which quantify the environmental and economic impacts of using PV. This type of knowledge is important when assessing and valuing the potential benefits of proposed future energy mixes that includes PV (Venture Onsite, 2016).

The scope of this research was aimed at filling this gap in knowledge, in particular bounding the work to investigate the energy requirements for Kuwait up to the highest peak loads, which occur during the summer months. This boundary was used to demonstrate the maximum peak loads that may be needed when using PV.

PV was selected as it can be utilised in diffused irradiance, unlike Concentrated Solar Power (CSP) that is highly dependent on Direct Normal Irradiance (DNI) (IRENA, 2012). Moreover, PV has the highest employment rate among other RE technologies (IRENA, 2016). Hence this research concentrated on PV technology because of its highest suitability in

the Kuwaiti conditions.

In this research, as an oil rich (especially GCC) country, the future PV adoption in Kuwait is assessed and valued economically and environmentally. Kuwait in this case is seen as an exemplar country and being representative of an oil-based economy. The outcome will assist decision makers in assessing and valuing the PV potential benefits of adopting PV from both an economic and environmental perspective in oil based economy countries.



## 1.4 Aim and Objectives

The aim of this research is to combine different approaches to enable the assessment of the economic and environmental benefits of adopting PV for electricity generation in Kuwait.

In order to achieve this aim the following specific objectives were identified:

1. Identify the future energy need and RE strategy for Kuwait.

In this objective, the current energy state and future needs for electricity generation in Kuwait as well as future projects plan including statistical data were analysed. The findings provided quantitative measures and behaviour of future electricity generation. Moreover current literature of future energy consumption projection was analysed to establish future energy scenarios for Kuwait.

2. Create scenarios for potential future energy mixes.

Based on the findings from objective 1, various scenarios are defined illustrating various levels of applying photovoltaic to generate electricity. A total of nine scenarios were identified. The scenarios include the current state as the baseline, the targeted percentage of electricity from photovoltaic to the maximum amount of electricity that is needed by PV.

3. Select techniques to measure environmental and economic impacts.

In this objective, the appropriate techniques are selected to enable the environmental and economic impacts to be evaluated. The findings showed that to analyse the scenarios a combination of techniques were required such as Levelized Cost of Electricity, Life Cycle Assessment and Pareto Front.

4. Create process and evaluate benefits of future energy mixes.

Using the identified techniques a methodology showing the process to be adopted to assess the benefits of large scale PV deployment is defined. The process is applied to the nine scenarios to quantify the economic and environmental benefits in order to have a comparison between the different scenarios created

The contribution to knowledge from this research is that the deployment of large scale PV technology provides both economic and environmental benefits to Kuwait. This holds true up to at least 30% of the maximum peak load of electricity.

The results have implications for other GCC countries with similar geographical, political and energy drivers; the methodology used in this research would be appropriate for these contexts.

## **1.5 Thesis Structure**

This thesis is divided into nine chapters; after chapter one, the introductory chapter, chapter two contains the literature review outlining the main drivers for RE globally moving the focus on GCC countries and then concentrating on Kuwait. Chapter 3 contains the Kuwait condition analysis that provides background on Kuwait energy state and establishes future scenarios. Chapter 4 is the description of the methodology used in this thesis. Chapter 5 and 6 are the methodologies applications for environmental and economic analysis respectively. Chapter 7 is the result and discussion of the analysis resulting from chapter 5 and 6. Conclusion and future work are in chapter 8.

## 2. LITERATURE REVIEW

In this chapter, first the environmental drivers of applying RE are presented followed by the new energy source need where the current main source globally is fossil fuel. 32.9% comes from Oil, 23.85% from gas, and 29.2% from coal (BP, 2016; World Energy Council b, 2016), which are non-permanent; this creates a driver for alternative energy. The focus is on oil rich countries as they are related and most affected by this concept; Gulf Cooperation Council (GCC) countries are contributing 23.6% of world's production of oil globally. As Kuwait has the lowest electricity tariff with the highest subsidies in GCC countries but at the same time it has the least current RE installations, there is a need for more extensive research to value the future potential of applying RE in Kuwait. This will also be beneficial for oil rich countries especially GCC countries since they share the same energy source infrastructure with similar energy policies (subsidies).

### 2.1 Drivers for RE

The main global drivers for adopting RE are described in this section. Starting with the main environmental impacts followed by the international political pressures and ending with the need for a new source of energy since current main sources are not permanent (energy depletion).

#### 2.1.1 Environmental Drivers

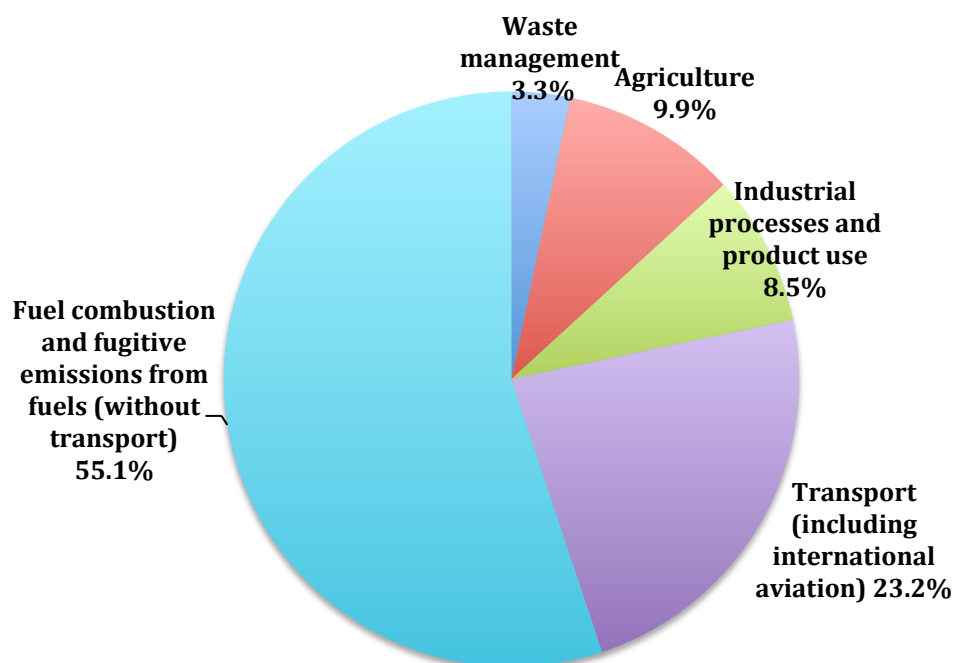
The main environmental impacts resulting from the use of the conventional fossil fuels focus on the challenges of global warming, air pollution, water and land pollution, thermal pollution and Greenhouse gases (GHG) are presented.

**Global climate** is heating up with a rate that can cause hazardous, irreversible consequences (Nicoletti, et al., 2015). Burning fossil fuels (oil) is responsible for over 34% of all carbon emissions that is the main Greenhouse Gas (GHG) in 2016 globally (IEA, 2016). Those emissions are trapped in the atmosphere raising the planet's temperature (National Climatic Data Center, 2013; Ming, et al., 2014). Human activities have resulted in a 25% increase in the total amount of carbon dioxide in the atmosphere (United States Environmental Protection Agency, 2013). Scientists claim that if these rates continued to increase, the planet will become warmer each century resulting in number of negative impacts (Olivier, et al., 2016; Ming, et al., 2014; Nicoletti, et al., 2015).

Some of the greenhouse gases occur naturally such as carbon dioxide, water vapour, methane

and nitrous oxide (NOAA, 2010). The proportions of these gases in the atmosphere have been rising which they are major factor in global warming (National Climatic Data Center, 2013; Mehta, 2015). Some of the GHG are paramount to live since they are responsible for trapping the infrared rays from the sun; hence keeping the earth warm to support lives. Nevertheless, excessive presence of such gases as CO<sub>2</sub>, sulphur and others has adverse effects on the environment, flora and fauna (Ledley, et al., 1999; Pichtel, 2016; Nduka, et al., 2016).

As shown in figure 2.1, energy consumption is the major contributor to greenhouse gas emissions. This motivates the deployment of alternative technologies for energy production to decrease the high emission due to fuel combustion. Since other industries that are not related to energy production produce smaller portion of GHG.



**Figure 2.1: Greenhouse Gas emissions by sector (Eurostat, 2016).**

Globally, CO<sub>2</sub> contributes approximately 60% of the GHG emissions and this percentage varies by country depending on its dependence on fossils to produce energy (Olivier, et al., 2016). Compared to the pre-industrial era, scientists believe that carbon dioxide levels (CO<sub>2</sub>) have increased by a significant level (Marchal, et al., 2011 (IPCC, 2014)). The concentration of CO<sub>2</sub> has changed from 280 parts per million in volume (ppmv) to 394 ppmv over a century, with an average growth of 2 ppmv/year in the last ten years. Oh (2010) stated that

the concentration of CO<sub>2</sub> has increased to approximately 400ppmv, a level that is beyond the 300 ppmv of the pre-industrial level. Notable increases have also occurred in levels of methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) (International Energy Agency, 2013).

Similarly, noting that most fossil fuel plants use water for coolant purposes, when the water combines with carbon, such harmful liquids as methanol and dimethyl oxide that affects humans, animals and plants (Speight, 2013).

**Air Pollution** is another driver; the combustion process of fossil fuels produces pollutants such as carbon dioxide, nitrogen oxides, sulphur oxide and other short chain hydrocarbons (Bae & Kim, 2017). When the combustion of hydrocarbons is incomplete the result is carbon mono-oxide as a by-product (Speight & Exall, 2014). It can cause headaches and affects people with heart disease adversely. Moreover, nitrogen oxides and sulphur dioxide (SO<sub>2</sub>) cause acid rains (Ombugus, 2016). They mix with water vapour in clouds to form nitric and sulphuric acid. These acids fall with rain increasing the acidity of rivers and lakes and hence affecting the plants and marine life. Acid rain also has a negative effect on crops, water bodies, human and buildings (Mehta, 2015; Ombugus, 2016). According to the (Union of Concerned Scientists, 2013; Khoo & Tan, 2006), two thirds of the sulphur dioxide emissions result from the power plants that use coal to generate electricity. Furthermore, combustion of fossil fuels forms particles that are suspended in the air such as smoke, dust, soot and other suspended pollutants. These particles are an irritant to the respiratory system (UCS, 2013; Speight, 2013). The effects of these particles are presented in number of papers (Mehta, 2015; Allen, et al., 2014), where they explain that these effects are toxic to human, both in adults as well as in children and decrease mortality levels (Prockop & Chichkova, 2007; Speight, 2013).

**Water and land pollution** can be caused by oil drilling (Pichtel, 2016), production and transportation (Kraus, 2011; EPA, 2014). Oil spills, such as the Gulf of Mexico oil spill, leaves water inhabitable and destroys the surrounding environment (Embach, 2016). For instance, according to National Oceanic and Atmospheric Administration U.S. Department of Commerce, oil spill has very advanced impacts on coral reefs that house a wide ray of organisms (NOAA, 2010). Nwilo & Badejo (2005) explains how oil spills in Nigerian water have had adverse effects on marine life, and eventually, the effects extends to land. In recent years, for example, in the Gulf of Mexico, oil spills have had multiple indirect impacts. For instance, the closure of fishing grounds has effects on seafood companies (Upton, 2011). This effects extends to economic problems where a considerable amount of revenue is lost both in

curbing the effect and lack of activities (Upton, 2011). Some enhanced oil recovery jobs such as hydraulic fracture (Brady, 2011) can pollute the underground water with chemicals or oil. Coal mining also is a major water pollutant. Coal holds pyrite, which is a sulphur compound (Union of Concerned Scientists, 2013). When water washes mines, it forms acids that can then leach to nearby rivers and lakes (Pichtel, 2016).

**Thermal pollution** occurs because of the combustion process of hydrocarbons to generate electricity produces a huge amount of heat (Fierro, 2013; Nordell, 2003) compared with other electricity generation processes. Because of the inefficiency of the process, part of the heat is radiated to the atmosphere causing a raise in the temperature in nearby atmosphere and water (Speight & Exall, 2014). The used coolant, usually water, gains heat in oceans and rivers (Allen, et al., 2014). That raises the temperature of the water affecting the aquatic eco-system (Union of Concerned Scientists, 2013).

### **2.1.2 Political Drivers**

Developed countries emit the largest amount of greenhouse gases globally accounting for more than 61% of total emissions as of 2014 (Olivier, et al., 2015); nevertheless, recently, emissions from developing countries have surpassed those of the developed ones and the emissions are still rising (International Energy Agency, 2013; Olivier, et al., 2016). Mitigation measure are now being undertaken to lower carbon emissions. The Kyoto Protocol of the UNFCCC is a climate agreement that is committed to lowering countries carbon footprints (United Nations, 2012; Council on Foreign Relations, 2013).

The Kyoto Protocol obligated developed countries to limit their GHG emissions by about 5% relative to 1990 by the 2012 first commitment period (International Energy Agency, 2013). 38 countries have agreed to participate in the second commitment period where different targets for each participant percentage of global emissions to ensure they decrease between 2013 and the end of 2020 (International Energy Agency, 2013). The main advantage of the Kyoto Protocol is that it creates a flexible mechanism between industrialized countries and developing countries to exchange carbon emission between each other (Council on Foreign Relations, 2013). The Kyoto Protocol has succeeded in making carbon dioxide a tradable commodity (World Nuclear Association, 2012). Provisions for international trading and the flexible mechanisms adopted by the agreement have managed to create and develop emissions trading schemes. According to the World Bank Group, in 2015, the total value of the global carbon market rose by 9% (to USD 50.93 Bn) compared to 2014 (Thomson Reuters, 2016).

### 2.1.3 Energy Source: Global Driver for Change

Regardless of the extensive research on alternative energy, fossil fuels are still the primary source of energy worldwide (EESI, 2014; Olivier, et al., 2016). Fossil fuel mainly comprises of oil, natural gas and coal products. Those fuels are combusted to generate heat that can be used directly or to generate steam that drives turbines and generators to produce electricity in power plants.

**Oil** is the major source of energy worldwide (PWC, 2013; UCS, 2013; Olivier, et al., 2016). It is found in underground reservoirs that are thousands of feet below the earth's surface (Lee et al., 2012). One barrel of oil can provide 5.2 MJ (The American Petroleum Institute, 2013). According to IEA, in 2016, the worlds' average daily consumption of oil was about 96 million barrels of oil (IEA, 2016). Figure 2.2 shows how world oil demand has increased over time. With the fact oil source is not renewable, and also is used in the production of many products (Olivier, et al., 2016), deployments of RE will help in saving the oil reserves and decrease the high rates of oil demand, hence help in avoiding oil depletion.

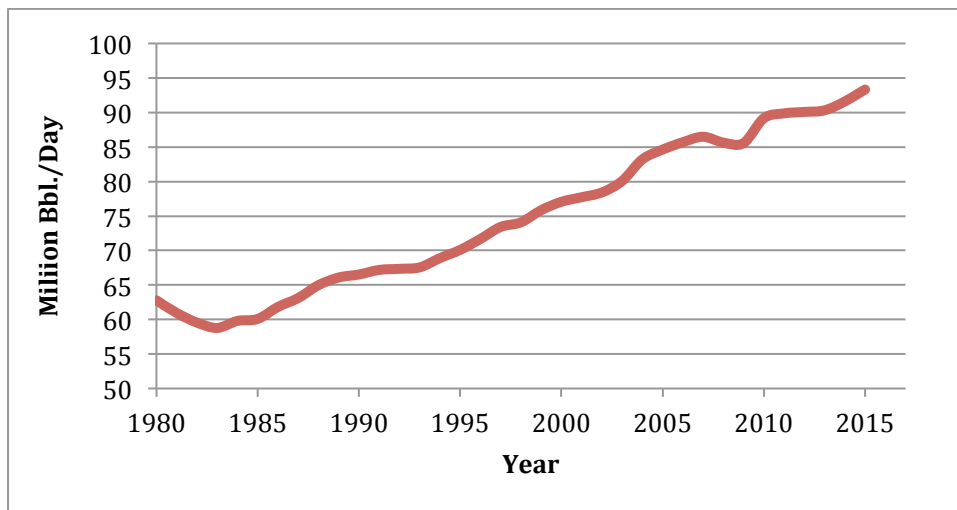


Figure 2.2: World oil demand (OPEC, 2016)

**Natural gas** is, in relative terms the least polluting non-renewable source of energy (Weiss et al., 2013; Sims et al., 2007; Bae & Kim, 2017). It can be found trapped in reservoirs under high pressures. It is used in industrial and commercial heating, and, increasingly, to fuel electricity generation (Logan, Heath et al., 2012). According to the API (2013), 170m<sup>3</sup> of natural gas produces energy that is equivalent to that from one oil barrel. The world consumed approximately 3,500 billion m<sup>3</sup> of natural gas in 2015 (BP, 2016).

**Coal** is a black sedimentary rock that mainly consists of carbon. It is extracted either by surface or deep mining (Craig & Vaughan, 1996). Coal is combusted to produce energy that is mainly used to generate electricity. Coal burns to produce 11.5 to 34.8 MJ/kg depending on the type of coal (The American Petroleum Institute, 2013; API, 2014).

The share of fossil fuel sources used to generate energy varies (Bhutto, et al., 2014). Natural gas's share of energy consumption increased by 1.7% in 2015 compared to 2014. Coal, on the other hand fell by 1.8% in 2015 due to a global decline in its production by over 4% (BP, 2016). Oil consumption increased by 1.9 million barrels equivalent to 1.9% in 2015 compared with 2014, which is an increase from the previous increase of 1.1% experienced in 2014 (BP, 2016).

## **2.2 GCC Context**

This section reviews the literature on RE globally moving the focus on the GCC region countries by illustrating the main differences and main GCC attributes.

### **2.2.1 Global Overview**

From a report titled *Global Trends in RE Investment 2016* written on behalf of United Nations Environment Program (UNEP), the amount invested globally in RE power amounted to over \$ 265.8 billion in 2015 compared to \$130 billion used in new coal and gas power plant in the same year. This serves as a pointer that the world is shifting toward green energy. This notwithstanding, RE technologies account for only approximately 10% of all the energy generation globally. Despite that fact, the 10% figure is substantial compared to previous years, since, it has allowed for the prevention of over 1.5 gigatonnes of CO<sub>2</sub> in 2015 equalling approximately 9% of CO<sub>2</sub> emissions in 2015 (Byrne, et al., 2016).

Decreasing GHG emission globally is one of the drivers for RE implementation in the world. The increased presence of these gases has detrimental effects on environmental sustainability drives; hence the demand to reduce their production. This was emphasised during the COP21 where all member countries committed toward achieving zero net emission by the second half of the century (Byrne, et al., 2016). To achieve this, reduction or total shift from use of fossil-fuel power is the most prominent strategy with RE sources such as wind, PV, hydro power and nuclear energy being viable replacements. Alternatively, countries could adopt carbon capture technologies. To ensure countries commit fully for reduction, subsidies on fossil fuels such as Export Credit Agency and subsidised financing of coal reliant power are



being phased out (KI-Moon, 2016).

Among the many negative impact of GHG is the rise in global temperature as was observed in 2015 which was termed as the hottest year in the recent past (Olivier, et al., 2016). High temperatures affect human and animal health, results to extreme droughts, rises in sea levels and increased flooding among other negative consequences. Such negatives are motivating governments to invest in RE (Buckley & Nicholas, 2016).

Another driver that is behind adoption of RE globally is the cost factor. The ultimate costs of implementing renewable energies are much reduced when compared to those of a conventional power plant. In Europe and Latin America where more RE projects have been undertaken, the costs of plants are relatively low (IRENA, 2016b). The costs of solar photovoltaics for instance are falling as advanced technologies are being developed especially in respect to crystalline silicon panels. Their prices have reduced from \$143 to \$122 per MWh between 2014 and 2015 (Byrne, et al., 2016). The costs are also lower because of the subsidies and incentives from government on renewable energy especially in European countries (Alberici, et al., 2014). The reduction in costs is also experienced in the operation and maintenance costs of renewable energies. These cost reductions are very evident in wind turbines and solar PVs as more efficient and higher performance turbines and solar systems are developed (IRENA, 2016).

Albeit the uptake of RE is global, different regions are driven towards adoption of the same by different factors. In Europe and Western world, besides the universally shared need for reduction in emissions, RE adoption are influenced also by reducing costs of implementing these alternative energies. Unlike in the GCC region where electricity price per capita is much reduced due to government subsidies, prices of electricity in Europe and western countries are relatively high; hence, the governments give incentive for off-grid electricity production. The unpredictable oil and gas prices also plays key role in influencing the need for alternative and reliable source of energy to have more predictable cost (IRENA, 2016). In contrast, in the GCC, the cost of conventional power plants is dominated by installation cost due to the ready availability of fossil fuels.

### 2.2.2 Gulf Cooperation Council Countries

Figure 2.3 shows the order of the world top producing countries, where Saudi Arabia takes the world biggest oil producer country producing 11.73 million bbl/day in 2016 then United States comes in the second place in production. Half of the top ten oil producer countries depend on oil as a major source to produce electricity, whereas Saudi Arabia, UAE and Kuwait depend completely on fossil fuels in generating electricity (The American Petroleum Institute, 2013; IRENA, 2016b).

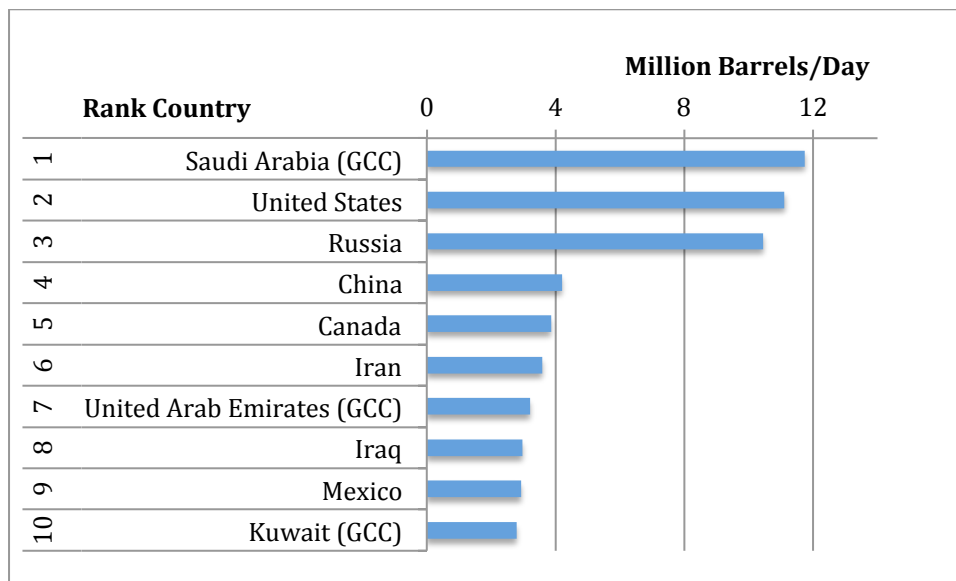


Figure 2.3: Top ten Oil producing countries, Source: Index Mundi (2017).

Oil production is particularly strong in Gulf Cooperation Council (GCC) members, which are six countries : The United Arab Emirates (UAE), Bahrain, Saudi Arabia, Oman, Qatar and Kuwait. GCC countries produce 23.6% on oil production in the world, also the GCC countries shares same political grounds and energy policies and have almost the same energy supply strategies (IRENA, 2016b).

GCC countries are driven by the need to free extra oil for export to support their economies that majorly relies on oil and oil-product exports (IRENA, 2016b). They capitalize on availability of solar resources and availability of extensive lands that are not viable for other purposes especially due to their desert nature. The increasing demand for electricity energy and clean water prompted by rising population in the region are also pushing governments in the region to opt for alternative energy sources to supplement the conventional sources.

Until 2010, the GCC countries have not been noticeable players in the renewable energy market. The level of operating renewable energy production plants and installations was very

limited as compared to the international market (EU\_GCC, 2013). As referred to by the Renewable Energy Readiness Assessment Report: the GCC Countries, (EU\_GCC, 2013) “investment in renewable energy started increasing in 2010 from very low levels”. However, in the late 2000s, the investment in RE has been notably intensified and the capacity of the operating renewable energy installations has increased (Ferroukhi, et al., 2013).

Before 2010, both the oil-rich GCC countries and the rest of the countries in the Middle East and North Africa (MENA) region have not been investing in large-scale renewable energy projects. Except for Iran and Egypt, with an installed capacity of 9.5 GW and 2.8 GW respectively (Arab Sustainability Association, 2013). There were almost no major renewable energy plants in operation in the MENA region in GCC countries in particular (MENA, 2013). The share of renewable energy in the MENA region's total primary energy supply was in the range of 1% from 2007 to 2010. This was primarily through the installed hydropower electricity generation capacity, and some use of biomass energy (Arab Sustainability Association, 2013).

After 2010, there has been a shift in the energy awareness of GCC countries. Most of the oil-rich countries have set targets for achieving diversification of their energy portfolio that include RE. Saudi Arabia defined their target as 54 GW of RE by 2032, broken down to; 41 GW Solar, 9 GW Wind, 3 GW from waste, and 1 GW Geothermal (Gulf Center for Strategic Studies, 2013). Dubai and Abu Dhabi (two emirates members of UAE) have taken a similar approach. Their targets are; cutting down CO<sub>2</sub> emissions by 1.5 tons per year through RE in Dubai, and generation of 7% of power through RE by 2020 for Abu Dhabi (EU\_GCC, 2013). The energy mix in the GCC countries is evident from the pronounced RE technologies that ranges from solar PV and solar CSP technologies (Ferroukhi, et al , 2013).

As for financing and investment, in 2011 alone, the UAE allocated USD 837 million for investment in RE, whilst Qatar invested USD 500 million in a PV facility. Additionally, The KSA invested USD 200 million in renewable energy R & D. According to Frost and Sullivan research, the financial strength of GCC countries is said to extend to approximately USD 100 Billion both in power generation and R & D projects (Frost & Sullivan, 2013). Currently, the UAE has the largest operating CSP in the world, outside the United States and Spain, Shams 1; having joined the 40% of the Middle East and North Africa (MENA) countries that operates CSP (Ferroukhi, et al., 2013; MENA, 2013) with a capacity of 100 MW as of 2013. The Kingdom of Saudi Arabia follows with a 723 kW capacity of PV and a solar power plant on the Farasan Island with a capacity of 500 kW (EU\_GCC, 2013).

### 2.2.3 Challenges for investing RE in GCC countries

There are many factors that reduce the attractiveness of investment in RE (MENA-OECD, 2011). One of these factors is the subsidy on conventional electricity prices. The subsidies result low cost of electricity for the consumers compared to the electricity from other sources such as RE, this decrease the motivation for alternative energy installation (Union of Concerned Scientists, 2013). In 2010, the subsidy on fossil fuel in Kuwait reached USD 2800 per capita, whereas it reached the level of USD 2500 in Qatar and the UAE meaning it is more economical to stay with the subsidized electricity (EU\_GCC, 2013).

The second reason is the political pressure against such a transition. With the largest oil reserves in the world, the GCC countries are home to many of the world's biggest Oil & Gas companies (IRENA, 2016b), most notably Saudi Aramco, which is the world's largest company in terms of proven reserves and production (Dutta, 2013). These companies are in a continuous endeavour to retain the high value of their product, which means they can exert political pressures towards slower adoption of RE technologies. As reported in Norton Rose Fulbright's report on RE in Saudi Arabia, Mr. Khalid El-Faleh – head of Saudi Aramco – expressed his concerns about *“the unrealistic drift towards an immediate transition to alternative energy sources”*. He believes that such drift can lead to reduced investment in the traditional energy sources that are “*tried and tested*” (Preston, 2012). This is a mere indication of the under-the-table political pressures that may constitute a realistic obstacle towards more investment in RE.

In addition to this, there is the problem of lack of regulating authorities in most of the GCC countries. As the Renewable Energy Readiness Assessment Report – executive summary – states; *“Most of the GCC countries lack a specific regulatory authority that is specifically responsible for RET projects”* (EU\_GCC, 2013). The presence of such authorities can lead to an easier approval process for the different projects, and it would entail the creating of a standard for such projects, which automatically leads to better outcomes and to increasing trust in RET. The lack of these regulatory authorities means that there is a minimal coordination between the different stakeholders in RE industry, and indicates an absence of a common framework that these projects should abide by (Ferroukhi, et al., 2013). Indeed, there are some ongoing efforts to cater for this gap, and an example of this is the effort undertaken by ERCA (the authority responsible for electricity and water in Saudi Arabia) to create a national renewable energy policy.

#### 2.2.4 Drivers for RE in GCC

There are many factors that can make GCC countries pay more attention towards making the RE a major source of the power generation structure. The first reason lies in energy security (Reiche, 2010). The huge existing oil reserves available in the gulf region – Saudi Arabia alone has one-fifth of the world’s oil reserves, and about 275 trillion cubic feet of gas – are coupled with an accelerating consumption.

The demand in Saudi Arabia is aimed to increase to 8 million barrels per day (oil) if the current energy generation and consumption structure remains unimproved – as predicted by Saudi Aramco (Preston, 2012). This is another factor to start relying on resources that are renewable rather than others which are finite in nature.

The second reason goes in the favour of increasing exports, especially with the increment of oil prices. The increased use of RE will lead to more oil production dedicated to export and will lead to lengthening the current status of “Oil Exporter” for those states as opposed to becoming importers (EU\_GCC, 2013). Although it is not urgent, for the longer term, it is good practice to test for the other resources of energy such as RE. (Arvai, et al., 2013 ;Reiche, 2010).

The economic diversification is another factor that favours investment in RE. The RE plants that will be installed will not only be used for domestic supply, they can also be used as export product to neighbouring countries in order to make better use of the favourable geographical position of the GCC countries. Hence, achieve a better economic diversification in terms of removing the dependency on fossil fuel exports (fossil fuel exports comprise about 40% of Saudi GDP, and the same applied to Qatar where gas exports account to approximately half of the national GDP (Preston, 2011).

A further reason to adopt RET, is creating a better market through offering a lot of high value jobs; R&D, Manufacturing, and local and international deployment which will lead to increasing the attractiveness of the area to international professionals, not just in the RE field, but also in all other supporting fields too (EU\_GCC, 2013). This is highly seen in an industry such as construction, which is one of the most preferred investment sectors in the gulf. The construction industry is closely tied to the RE industry as all of the major RE projects require high-value and highly technical construction projects and infrastructure to support them (Ferroukhi, et al., 2013). In addition to this, adopting *Green Code* in the current construction projects increases their value and makes them an attractive investment. (Gulf Center for

Strategic Studies, 2013).

Due to the previous factors mentioned, GCC countries start planning projects in RE field. Table 2.1 shows a brief of the future plans to implement RE technologies in the GCC countries. The Kingdom of Saudi Arabia plans to install a 54 GW capacity by 2040, with a concentration on solar energy of 41 GW, 9 GW of wind 1 GW from geothermal and 3 GW from waste-to-energy (Venture Onsite, 2016). Comes in second, the United Arab Emirates, with 24% of Dubai's final energy from renewables in 2030, with solar PV contributing 5GW, and 7% of Abu Dhabi's final energy from renewable in 2020. Qatar has announced 20% (1800 MW) capacity by 2030, and Oman has announced a similar 100 – 200 MW of PV. Kuwait has planned a 15% generation of renewable capacity by 2030 (IRENA, 2016b).

**Table 2.1: GCC Planned RE Implementation plans (IRENA, 2016b).**

<b>GCC country</b>	<b>Total RE (2014) (MW)</b>	<b>Total RE target in 2030 (GW)</b>
Bahrain	0.6	0.7
Kuwait	0.2	10.9
Oman	0.7	2.4
Qatar	28.2	1.8
Saudi Arabia	25	29.3
United Arab Emirates	134.9	33.3

## **2.3 Kuwait Drivers for PV Technology**

Kuwait is experiencing increases in its population, which currently sit at 4 million (Population Reference Bureau, 2016) people with an annual growth rate of approximately 3.9% (Stiftung, 2014). Similarly, the country has experienced temperature increases due to climate changes globally. Its reliance on fossil fuel as its primary source of energy has seen it contribute significantly to GHG emissions (IEA, 2016). All these facts have contributed to pressure on the government to complement its energy power production with renewable technologies.

It is worth noting that Kuwait is endowed with natural resources, especially the proven oil products. Such resources have been very influential in its energy production. Indeed, it has managed to avail energy to its population at a world lowest price of 2 fils/kWh or approximately \$ 0.7 cent/kWh (Fattouh & Mahadeva, 2014; IRENA, 2016b). Nevertheless, population growth has pushed the energy demand to an annual increase at a rate of between 6-8% (Bedir, 2016); thus, the production capacity in the country is approximately equal to the energy demand. To manage this demand and support the infrastructural projects initiated by the government, new sources of energy are always in need. Research has shown that, of all the GCC countries, Kuwait has the lowest RE installed (0.2 MW) (IRENA, 2016b). Hence, increasing production from these sources would see the country ease some of the pressure on its energy sector. Practically, one of the viable RE source for the country is PV solar energy though wind and nuclear energy are also viable options.

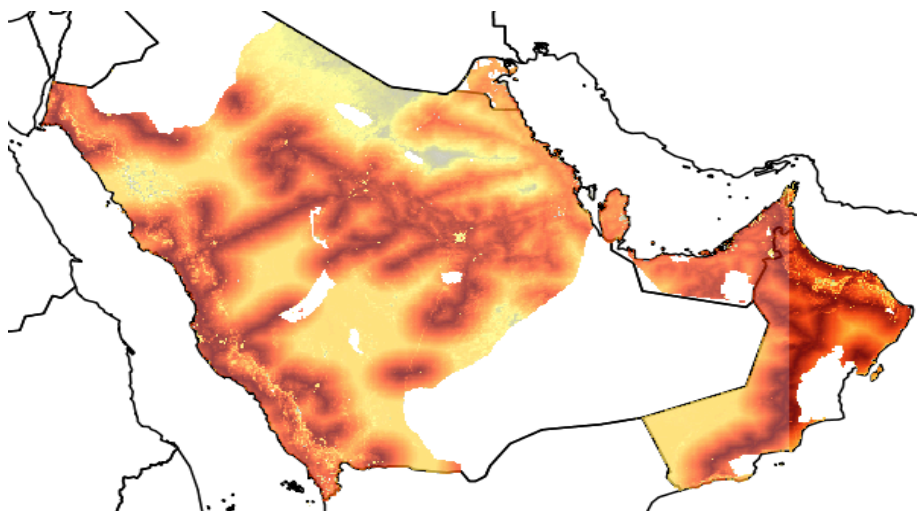
To achieve its objective of supplementing its power mix, the government of Kuwait is advancing a number of policies aimed at promoting implementation of RE (IEA, 2016). By implementing the RE agenda, it will also ease some pressure on the oil industry; hence, help in increasing oil exports. Indeed, it has been reported that the government's target is to achieve 15% power production from RE by 2030 equalling to 3282MW based on future expectations (KISR, 2016). As a major step of the 15% target the Alshagaya project is being implemented as well as other potential RE projects which are aimed at reaching the 15% target by 2030.

The goal of the Alshagaya project is to produce 2000 MW from renewable technologies hence, meeting the increasing demand with reduced emissions. The 2000MW is planned in three stages where 70MW, 930MW and 1000MW are the expected to be produced in stages 1, 2 and 3 respectively (KISR, 2016).

Being located in the global Sunbelt (between 35°N and 35°S) Kuwait as a member of the GCC countries has high solar resource and with reducing costs of associated technologies, there is a high potential of implementing photovoltaic energy (Ramadhan & Naseeb, 2011). According to EPIA (2010), the GCC region experiences highest solar irradiances and has over 60% of the region's surface area being suitable for utility solar PV. Figure 2.4 shows the suitability of applying large scale PV plants in GCC countries with these facts, it is noted that if only 1% of the area is utilized for PV energy generation, it is expected to produce approximately 470 GW of additional installed capacity (Kearney et al., 2010). This is just an example of the potential the region has when it comes to PV that could help in addressing the increase demand for power.

From the job opportunity side, PV is the largest employing RE technology where Concentrated Solar Power (CSP) is second with 31% of that job opportunity (IRENA, 2016). Moreover, CSP is highly dependent on the Direct Normal Irradiance (DNI). This is unlike photovoltaic that can work with scattered and diffused irradiance (IRENA, 2012). This factor is important when considering Kuwait weather conditions.

Furthermore, PV technology produces its largest amount of electricity at the highest irradiation times, which, in Kuwait, happens in summers. This is most suitable for Kuwait because the maximum electricity peak loads occur in summer time where it is the contrary in Europe (European Commission, 2014). Meaning the PV works in its highest efficiency when needed the most.



**Figure 2.4: PV (utility scale) suitability in GCC; The map illustrate the suitability scores between 70% and 100% (from light yellow to dark red) (IRENA, 2016).**



### **2.3.1 Kuwait Economic Drivers for PV**

Studies performed on the Kuwaiti environment estimate the annual solar irradiation at 2100-2200 kW/m<sup>2</sup> (Ramadhan & Naseeb, 2011), with an average daily irradiation on horizontal surfaces of 5.9 kWh/m<sup>2</sup>day (Bou-Rabee & Sulaiman, 2015; European Solar Test Installation, 2013). The high irradiation in Kuwait means a greater efficiency of the solar panels compared with regions with lower solar irradiation and a better economic viability.

In order to determine the benefits of installing a PV system, the LCOE of that system should be compared with the average cost of conventionally produced grid-electricity. Research papers mention (Ramadhan & Naseeb, 2011; Bourabee & Sulaiman, 2015), the cost of producing conventional grid-electricity in Kuwait is around KWD 0.034 (\$0.12/kWh) – other research mention it is around KWD 0.045-0.060 (\$0.15-0.12/kWh) (Al-Rashed, et al., 2016). Even when the lowest cost number (\$0.12) compared to the latest aforementioned LCOEs of PV-generated electricity in 2010 and 2013 (Ramadhan & Naseeb, 2010; Hadi et al., 2013) \$0.16 and \$0.09 respectively, it can be concluded that the PV-generated electricity can achieve grid-parity. Therefore, it has become economically viable for the national electricity generation strategy to put more focus on utilizing PV technology in this process.

It also has to be noted that the mentioned cost of grid-electricity (\$0.12/kWh) is calculated at a price of \$50/barrel of oil (Ramadhan & Naseeb, 2010). However, with the current oil prices around \$54 barrel of oil in 2017 (OPEC, 2016), and with the cost of fossil fuel contributing to about 68% of the cost of convention grid-electricity (Ramadhan & Naseeb, 2010), the cost of generating conventional fossil-fuel-based grid-electricity is directly proportional to the increasing oil prices.

It was found that installing a 1000 MW photovoltaic power station can reduce the total annual [fossil fuel] energy consumption by about 15% (Alotaibi, 2010). Additionally, such a system is expected to reduce the average monthly peak load by approximately 0.76 MW for each installed 1 MW of photovoltaic electricity generation facilities (Alotaibi, 2010).

However, this is only the direct benefit; the market value of the electricity generated by the PV system. There are other benefits, including environmental benefits, which will be discussed in the following section.

### **2.3.2 Kuwait Environmental Drivers for PV**

GCC countries are considered highly vulnerable to the effects of climate change (Al-Olaimy, 2013). Similarly, the increasing population and accelerating industrial activity is contributing to air pollution (Science for Environmental Policy, 2010). The increase in global temperature constitutes additional threat to the local water resources (Bhutto et al., 2014).

Additionally, studies estimate the total ecological footprint of GCC countries at 11.68, 9.72, and 8.44 gha/person (“global hectare” is one biologically productive hectare at the world average that should be regenerated due to the consumption of one person) for Qatar, Kuwait, and UAE respectively (Bhutto et al., 2014). This is relatively high, compared to the world average of 2.70 gha/person.

The Sahara desert and Arabia desert are commonly considered the most appropriate locations for the solar power stations due to the minimal cloud cover and the very little biomass (Hernandez, et al., 2013). Side effects on the local species include increased mortality rate of some organisms due to soil disturbances and roads (Hernandez, et al., 2015; Armstrong, et al., 2016), or exotic invasions of new species facilitated by the changes in the site, which can affect the native species on-site. In addition, the environmental toxicants required for the operation of the power plant (e.g. dust suppressants, rust inhibitors, antifreeze / cleaning agents etc.) may have long-term consequences on the local biodiversity (Hernandez, 2016).

On the other hand, photovoltaic utility-scale power stations have low levels of water consumption ( $0.02 \text{ m}^3/\text{MWh}$ ) (Hernandez, 2016) and are only said to consume relatively higher amounts during the construction stages as noted by Hernandez, et al., 2013 and Klise et al., 2013. Furthermore, due to the clean nature of photovoltaic technology, modules by themselves have low health impact while operational (First solar, 2014). However, a wide range of researchers (Larsen, 2009; Environment Canada, 2012; Auer, 2015) argue that, during the decommissioning stage of the plant, the modules have to be recycled to prevent contamination due to the toxic materials within the cells.

Fossil power stations, especially in the GCC countries are always under intense pressure due to the high demand for power (IRENA, 2016b). Particularly, in Kuwait, the power is in high demand in air-conditioning (MEW, 2014) and up-stream industrial consumption (Hashem, 2013). With Solar power plants, as noted by (EU\_GCC, 2013; IRENA, 2016b), the pressure is bound to ease; hence, the alternative power source can increase their production capacity

and load efficiency.

**Water consumption** from photovoltaic utility-scale power stations are in low levels (0.02 m<sup>3</sup>/MWh) which is primarily used in panel washing and dust suppression (Hernandez et al., 2013; Klise et al., 2013). This is opposed to Concentrated Solar Power (CSP) plants where there is an extensive usage of water in wet cooling for example (3.07 m<sup>3</sup>/MWh). This will avoid unnecessary water consumption since there is no major natural fresh water and almost all of the water is coming from desalination power plants

**Health toxicity** are in low levels. Due to the nature of PV technology, modules by themselves have low health impact while operational (Moss, et al., 2014). However, during the decommissioning stage of the plant, the modules have to be recycled to prevent contamination due to the toxic materials within the cells (Hernandez, et al., 2013).

On the other hand, during use phase, there are many positive health factors resulting from solar power plants, especially when compared to traditional energy sources. This fact arises from the reduction in the released toxic materials into the environment as compared to traditional plants and other alternative energy sources (Kannan & Vakeesan, 2016). For example, solar power plants release 50 – 1000 times less of mercury (Hg) into the surrounding environment than the traditional electricity generation methods. The same applies to emissions of NO<sub>x</sub> and SO<sub>2</sub>, which are orders of magnitude smaller than the emissions by traditional energy sources (Turney & Fthenakis, 2011). All of those aforementioned toxic emissions are hazardous to human and wellbeing.

The **GHG emissions** of PV power stations during use phase are very low compared to conventional stations (Yessian et al., 2013). Studies show that the GHG footprint can vary widely from one location to another. One study shows that the life cycle GHG emission for three PV stations in China (each 100,000 kW in capacity) approximately equal to 12 g.CO<sub>2</sub>/kWh (Varun et al., 2009). This particular issue is very important when the general increase in CO<sub>2</sub> emissions from the GCC countries is taken into consideration; from 1991 to 2006, the CO<sub>2</sub> emissions are reported to have increased by 50%. Additionally, the Total Primary Energy Supply (TPES) per capita are particularly high in the GCC countries, with a 9.48 TOE (ton of oil equivalent) per capita in Bahrain, 19.93 in Qatar, and 9.53 in Kuwait, compared to an EU average of 2.42 TOE per capita (Doukas et al., 2006).

### 2.3.3 Other Drivers for PV in Kuwait

PV is **efficient in land utilization**. Photovoltaic power generation have been seen to be effective in desert areas where the daily irradiation, solar inclination angles among other factors are favourable (Elhussain & Abdel-Magid, 2016). Kuwait, is one of the GCC countries with a large desert area makes it a potential land for PV. According to World factsheet (2014), Kuwait's available arable land is only 0.62% of the total land. The rest of the land is hot and dry. Similarly, with over 98% of the total population residing in urban areas, the country has a vast land for installation of photovoltaic power stations (The World Factbook, 2014). Which relieves some pressure on the fossil fuel power energy (Bringezu, et al., 2014).

**Employment opportunity**, resulted from generation of PV and renewable energy in general, is increased because of the demands of high-tech devices, extensive land for setting up the power stations, work force to work on those areas and many other requirements. All these means that the introduction of photovoltaic power energy would open up new job opportunities for people who are still unemployed; hence, reduce the unemployment level (The World Factbook, 2014). PV is the largest employing RE technology where Concentrated Solar Power (CSP) is lowest with 31% of that job opportunity (IRENA, 2016). The employment opportunities in Kuwait range from field installation, distribution works and the general maintenance in the solar power stations (IRENA, 2016b). The proceeds from this new energy sector and the amount relieved from the oil sector to assist Kuwait's economic performance to match its GCC peers. Similarly, in addition to providing new platforms for job creations, the alternative renewable energies would serve as a fiscal buffer in the case of an oil price shock (International Monetary Fund, 2013).

In **durability and reliability** concerns, unlike other sources of energy, photovoltaic devices are to have a longer life, which can extend to approximately 30 years. All this time manufactures given an assurance of 90% capacity for the first 10 years and to almost 80% in the preceding years (Dia, et al., 2016). The durability and reliability factors are fostered by the increasing demand for these devices. This increases competition from different manufacturing industries that strive to beat their competitors by improving quality and efficiency. These manufacturers are applying longer-term tests for different weather conditions and degradation factors (Phinikarides, et al., 2014). The total sum of such competition results more reliable quality of the products for the consumer. In Kuwait, with conducive environment and quality devices, the efficiency levels described by the manufactures are expected to be achieved; thus making photovoltaic power applications very

reliable (Ramadhan et al., 2012).

The durability and reliability of photovoltaic systems are also warranted by the fact that the field is well researched and has been tested and implemented (Phinikarides, et al., 2014). Among the most researched and tested factor is the effect of dust on the performance of PVs. The investigations on this field have been performed in the laboratories (Niel, et al., 2012; Rajput & Sudhakar, 2013). Noting that Kuwait is windy and dusty (Ahmed et al., 2014) hence, there are a number of cleaning methods that have been advanced that help in maintaining the PV (Zielnik & Dumbleton, 2012). This means that photovoltaic power generation is applicable in Kuwait and would benefit the country a great deal.

In respect to electric power, security comes in different forms. Such things like **domestic energy security**, ability to have control over distribution and reliability of the power, environmental and human safety among others. According to IRENA (2016), there are reasons that call for alternative source power. Among these reasons is the increasing demand of electricity for domestic use (International Monetary Fund, 2013; Ameer & Krarti, 2016). Noting that the number of households requiring regular and reliable power supply is increasing due to increasing population, higher usage of a diverse range of electric appliances among other things, one route to try is the installation of photovoltaic power. Similarly, a combination of extreme weather conditions, intensive government subsidies of electricity and high levels of water desalinization has also increased the demand for alternative source of energy (Solar GCC Alliance, 2014). Solar power energy has less emissions than conventional oil power plants and less cost than oil power plants based on claims from studies done in other regions such as Europe and China; hence, give an assurance of domestic energy security even when the conventional type of energy is diverted toward other projects (Dicks, 2011), thus warranting power interruptions.

The security also comes about since photovoltaic power generators can be sited on land unlike conventional power plants that need to be set by water source; they qualify as ideal for distributed power generation. This feature allows them to minimize the power loss witnessed in the networks of the conventional power supply as a result of long distances between power generation stations to the consumption points (Ramadhan et al., 2012). Similarly, the low capital expenditure required to set up small-scale photovoltaic power stations makes them suitable for domestic power supply (Ramadhan et al., 2012)..

Another factor that make photovoltaic power generation in Kuwait is the fact that solar

energy peak power generation coincides with seasons (summer) when energy demands are at the peak. Therefore, it becomes a suitable renewable energy technology (Ramadhan & Hussain, 2012).

## **2.4 Summary and Research Gap**

In this chapter the main drivers for PV were illustrated in terms of environment, political and physical properties. Most of these drivers are related to fossil fuels especially oil being unsustainable global main source with high environmental impacts. This results the creation of new policies to adopt RE. However, oil rich countries, especially GCC countries have oil based economies gaining their wealth through oil which is challenging when looking to RE. The potential of large-scale RE source in GCC cannot be overlooked, GCC countries start their initial plans recently, starting from 2010, with lack of experimental experience resulting in need for more research. GCC region have large amount of irradiation especially compared to Europe, with this in mind, the concentration of PV studies is more in Europe compared to GCC region. Another reason makes PV a primary RE option is that it works with its highest efficiency in high irradiation times. This coincide with the highest peak loads, in GCC, in summer. Kuwait, a member of GCC, has the highest cost in electricity production among the other GCC countries, nevertheless, it offers the highest subsidies (lowest electricity tariff) making it the greatest beneficiary of adopting PV to lower the cost of electricity. Moreover, Kuwait currently has the least current RE plants in the GCC with a lack of studies valuing PV especially in future terms. This research will quantify the environmental and economic benefits of applying PV for future mixes in Kuwait as a GCC country. This will assist decision makers in Kuwait and GCC countries in establishing the most suitable policies and scenarios.

Most photovoltaic research has not focused on the GCC geographic region and very little research has taken into consideration government energy policies or where resources such as oil is predominant. In Kuwait, electricity is subsidized and conventional oil plants are the main source of electricity due to the abundance of oil. Limited studies in countries such as Kuwait have examined the economic and environmental impacts of deploying large-scale photovoltaic technology. Of the studies that have been undertaken concerning the use of photovoltaic energy generation in Kuwait and the economic and environmental impacts, have concentrated on the use phase and not the whole life cycle of photovoltaic plants. Moreover, there is lack of studies addressing the impact of the consequences of energy storage.

Based on these findings the scope of this research is to investigate the economic and environmental life cycle impacts of deploying large scale photovoltaic in GCC countries. This fills a gap to enable GCC countries to ascertain the value that PV can offer. In this research, an essential methodologies combination is made that quantifies the economic and environmental impacts and suits GCC region characteristics including their energy policies and geographic location. This, in this research, is applied on Kuwait as an exemplar of other GCC countries.

### **3. KUWAIT CONDITION ANALYSIS**

The need for reviewing electricity consumption history and the future expected consumption is important for the governments in order to re-evaluate their power source, and also to determine whether the source is sufficient and reliable in the long-term. In Kuwait, in order to expect future electricity need and to value future energy mixes, specific scenarios have been established based on Kuwait current energy state and future expectation.

This chapter will focus on Kuwait's electricity sources, consumption history, the duration of the peak loads and the increase in electricity consumption. Finding that the very first reason of the continuous building new power stations is to increase the electric capacity to cover the maximum peak load in summers (figure 3.3). Kuwait's future power plans is presented showing that it still mainly depends on conventional power plants with the exception of the Alshagaya future project which is a renewable source (Venture Onsite, 2016). As illustrated in the literature review, Kuwait has high potential of benefits economically and environmentally of applying RE with PV being the highest potential benefits, beside Kuwait's commitments to apply RE. Kuwait government commitments are using 2030 as a target year, electricity consumption and peak load for year 2030 is estimated based on current literature and future expectation. Nine specific scenarios for 2030 representing different energy mixes (percentages of maximum peak load) of conventional plants with PV are defined. These scenarios are aimed at estimating a value for each scenario and quantifying the economic and environmental benefits for the proposed energy mixes.

#### **3.1 Kuwait Electricity Current State**

Kuwait's traditional sources of power are oil and natural gas that are manufactured, produced, transmitted and distributed by the government (Alsayegh et al., 2013). Kuwait is among the oil-endowed countries, with its reserves predicted to continue being resourceful for approximately the next 100 years as reported by Matabadal (2013). Like any other GCC country, Kuwait experiences very hot spells reaches 50 °C (Alsayegh et al., 2013) in summers. This increase the need for electric power to cool the houses, offices and other areas that are habited especially at summer times. A considerable amount of power is used in the cooling systems; both in homes, offices and all other places that have human activities besides other domestic uses.



The demand for power is expected to grow due to the increasing population in the country, estimated to be slightly above 4 million people in 2016 (Wood & Alsayegh, 2014; Population Reference Bureau, 2016). Kuwait has high growing maximum peak load rates at an average of approximately 6% annually (MEW, 2013). Hence, the development and expansion of the power generation facilities is one of paramount importance to the Kuwaiti energy supply to avoid blackouts during peak times.

The installed capacity grew from 2.25 MW in 1952s from the first power station in Kuwait the Shuwaikh power station into 11640.8 MW by 2008 (~11.6 GW) (Ministry of Electricity and Water - Kuwait, 2009). Figure 3.1 shows the increment of the installed capacity made by the Ministry of electricity since 2000.

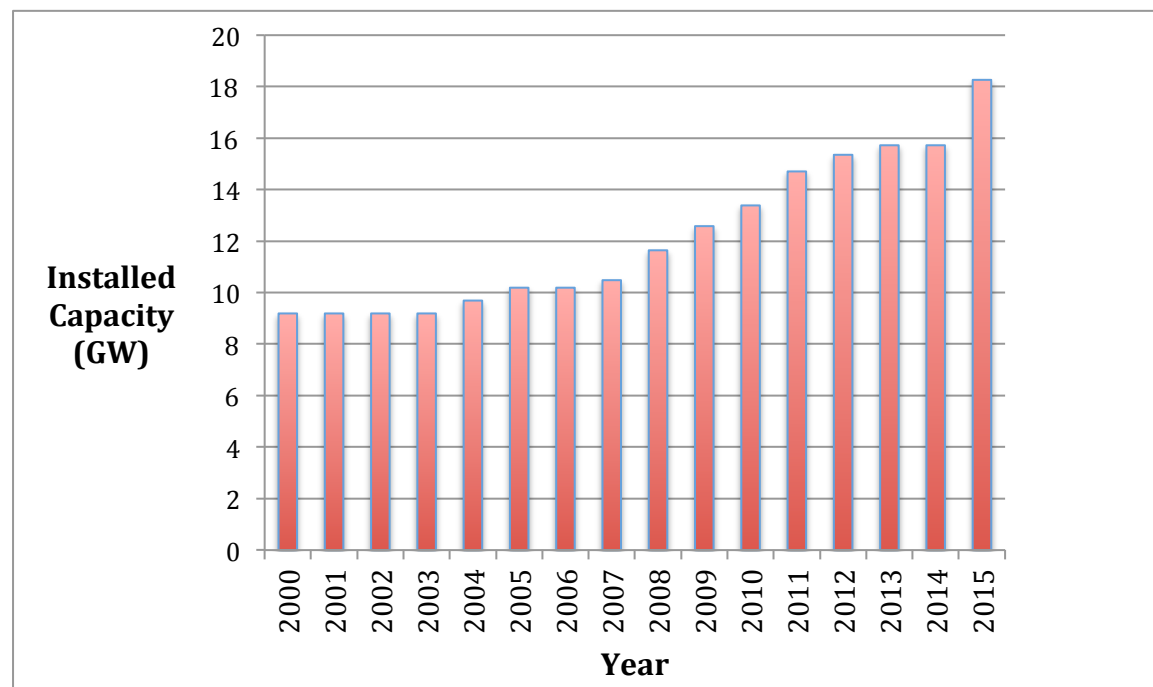
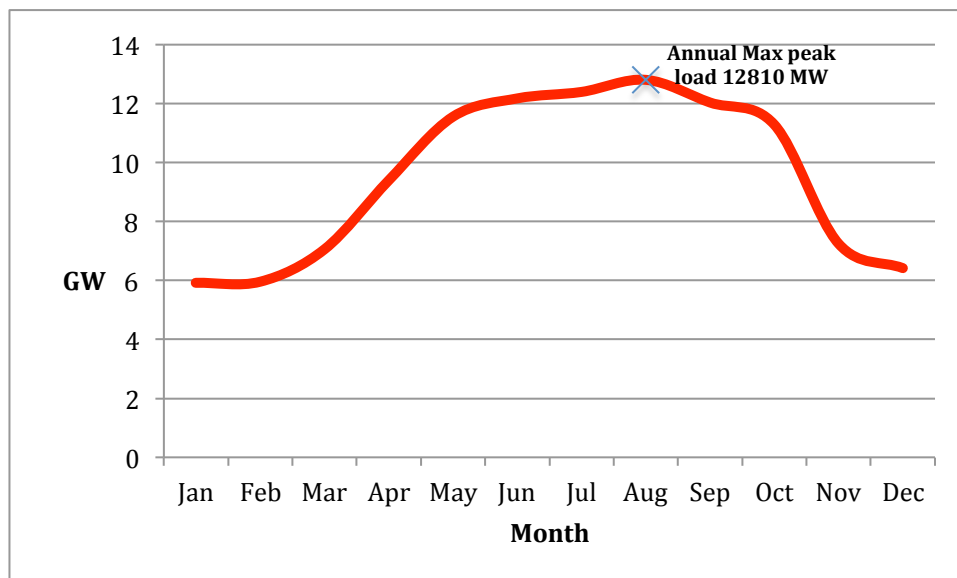


Figure 3.1: Development of Power Stations Installed Capacity from 2000 to 2015 (MEW, 2016).

Currently, as in 2016, the total capacity is 18.3 GW (MEW, 2016) from eight power stations that are running. They are shown in table 3.1.

**Table 3.1: Current installed capacities of Kuwait Power stations as in 2016 (MEW, 2016).**

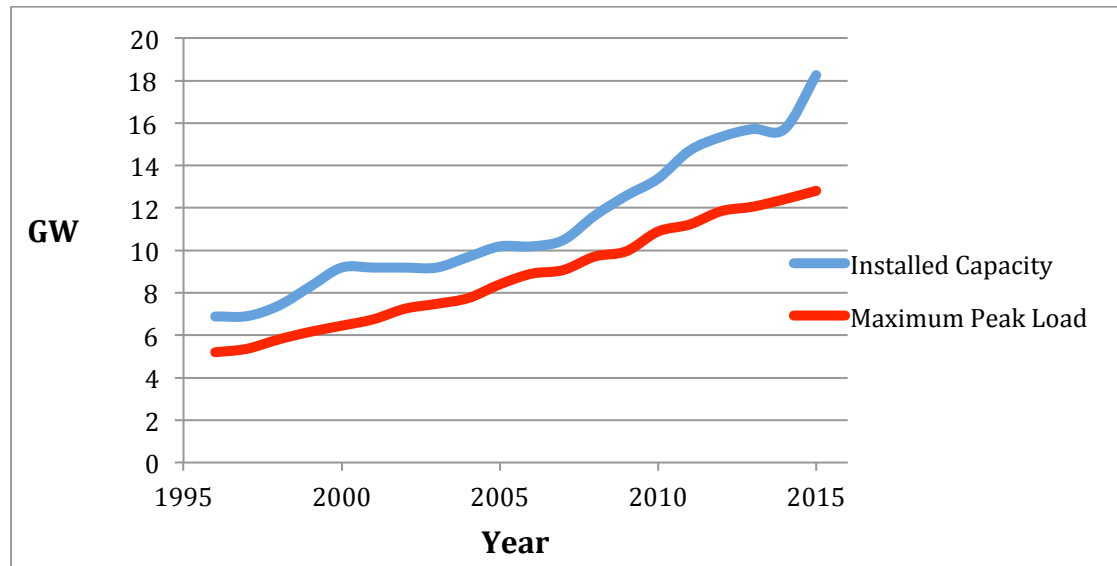
	<b>Power Station</b>	<b>Installed Capacity (MW)</b>
<b>1</b>	North Shuaiba	875.5
<b>2</b>	South Shuaiba	720
<b>3</b>	Eastern Doha	1158
<b>4</b>	Western Doha	2541
<b>5</b>	Az-Zour South	5805.8
<b>6</b>	Az-Zour North	1540
<b>7</b>	Sabiya	5366.7
<b>8</b>	Shuwaikh	252
	<b>Total</b>	<b>18259</b>



**Figure 3.2: Maximum Peak Loads for year 2015 (MEW, 2016).**

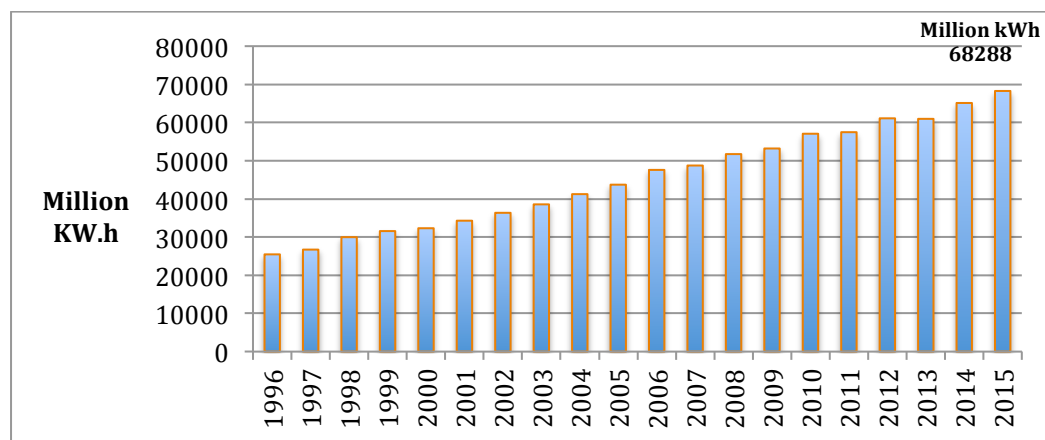
The main reason of this continuous increment of power capacity in Kuwait is to overcome the maximum peak load in summer days to avoid blackouts (figure 3.2). For example, in 2005, the installed capacity was 10,189 MW, in 2015, the maximum peak load in the summer

reached 12,810 MW. This could result in blackout days during that summer if no new power plants were built in that 10 years period (MEW, 2016). The Ministry of Electricity, in 2015, achieved 18,259MW to avoid such blackouts. Figure 3.3 shows the increment of the installed capacity to cover the maximum peak load from 1996 to 2015. Basically, in a twenty year period it has almost doubled.



**Figure 3.3: Installed Capacity and Maximum Peak Load, Data from (MEW, 2016).**

Energy Consumption is another reason besides covering the maximum peak loads; the annual consumption of energy generation (kWh) is in continuous increase. Starting from Kuwait's first electricity generation in 1952 with an average of 6% in the last 15 years. Electric consumption has grown 111% from 2000 to 2015 to reach 68,288 million kWh per year (Ministry of Electricity and Water - Kuwait, 2009; MEW, 2016). Figure 3.4 shows the increment of the annual electricity consumption in the last 20 year.



**Figure 3.4: Generation of Electrical Energy (MEW, 2016).**

GHG emissions, due to this energy consumption, are increasing annually. According to the IEA, CO<sub>2</sub> emissions from fossil fuels in Kuwait amounted to 84.1 Mt in 2013 (International Energy Agency, 2015). Most of CO<sub>2</sub> emissions come from the energy sector as indicated by the United Nations Framework Convention on Climate Change's report on Kuwait emissions. The report shows that the energy sector accounted for 95.35% of the emissions in Kuwait (UNFCCC, 2013). Figure 3.5 shows GHG emissions from fuel combustion from 1971 to 2013 in Mt of CO<sub>2</sub>. It can be seen that Kuwait emissions have increased by over 200%; over 3 times more than those of the world's increase which stands at 56%.

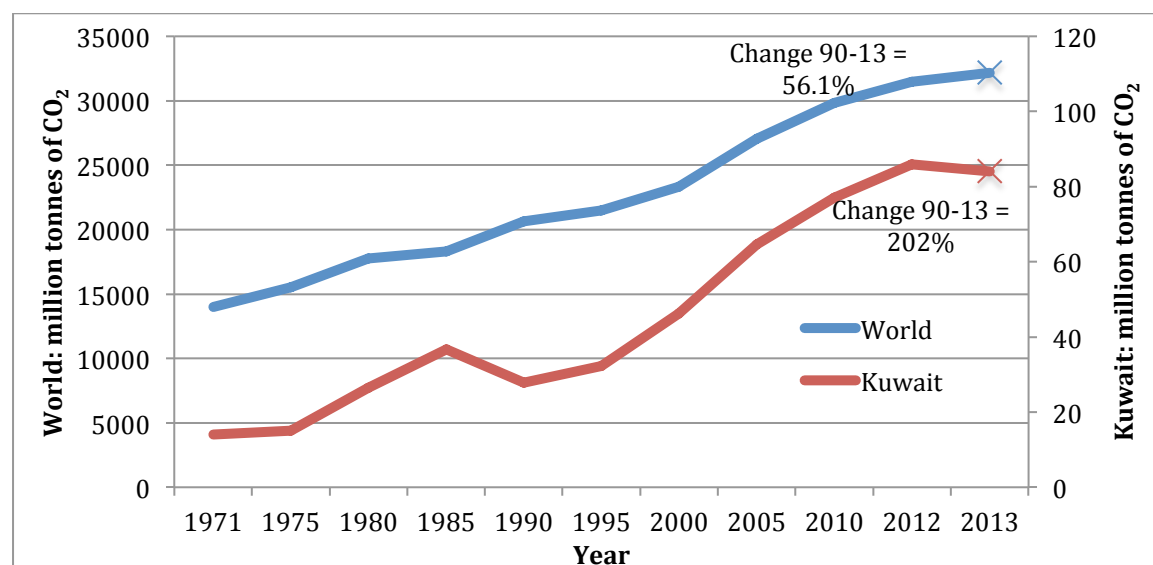


Figure 3.5: CO<sub>2</sub> emissions from fuel combustion from Kuwait compared with world emissions (IEA, 2015).

### 3.2 Future Projects Plan

As illustrated in the previous section the demand for electricity in Kuwait has continually increased (MEW, 2016), to meet consumption and in particular to avoid summer blackout when maximum peak loads occur. This fact is partly credited to the increased population that is caused by both local increase and also the increase from immigrants employed and working in different sectors. As of 2015, the country's population has increased to over 4 million. With this increasing population, demand for electricity for cooling and other domestic needs has increased. Demand is also prompted by the infrastructural development undertaken by the government especially in the construction industry (IEA, 2016).

To cater for these demands, Kuwait's government has been expanding its energy sector from an initial production capacity of only 2.25 MW in 1952 to the current installed capacity of ~18.3 GW (MEW, 2016). Most of the projects that the government have been undertaking are based on fossil fuels (oil), but going forward, the government is aiming to supplement the electricity generation with 15% RE by 2030.

The current electricity power projects in Kuwait (under implementation) aimed at increasing the existing installed capacity include the Stage 2 of Sabiya Power and Distillation Plant site that is expected to have an installed capacity of 500 MW. A future project that is expected to be complete by 2019 is the conversion of the third stage Az-Zour south gas turbines to combined cycle plant (CCGT-3). The conversion will upgrade the plant by adding 250 MW to the already installed capacity (MEW, 2016).

Another project being undertaken by the government is the Alshagaya Initiative entered electricity grid plan in 2011 and is expected to fully be completed by 2030 where it is expected to help the country achieve a national target of 15% of power from RE. The project has a 2000 MW capacity derived from multi-technologies including solar thermal technology, solar PV technology and Wind power technology. The first phase of this project yields 70 MW with 10 MW coming from solar PV technology, 10 MW from wind power technology and 50 MW from CSP technology and is expected to be complete by 2017 (KISR, 2016) The reason for these different amounts of RE technologies capacities is not clear. Moreover, the 930 MW and 1000 MW (phase two and three respectively) RE technology capacities are not available in public domain, which needed clarification. The interview questions such as: What are the future RE plans for Kuwait?, explain the "Alshagaya" project (not in public domain) and what are the interviewee's personal viewpoint on the adoption of RE? were

defined to ascertain future plans and views which were not available in the public domain. Through initial interviews with two of the leading Kuwaiti experts (One from Ministry of Electricity, the other from the Kuwait Institution for Scientific Research) (a full list of the questions are provided in appendix A), it was found that the main aim of phase one is to test these three RE technologies to assist in choosing the most suitable technology for phase two and three of the project. One of the other reasons for choosing the capacities for each technology in phase 1 is because of economic reasons related to manufacturing quantities. The second phase is planned to yield 930 MW and the final phase 1000 MW (Venture Onsite, 2016). Moreover, interviewees were asked about Kuwait future electricity plans and personal point of view about research undertaken.

Stage three of the Sabiya Power and Distillation Plant site is aimed at upgrading the facility and by adding to its capacity by 750 MW, it is currently underway and is expected to be in service by 2022. The project involves supplying, erection, operationalizing and maintaining the existing gas turbines operated by the combined cycle plant. At the end, the capacity of the plant is expected to reach 1800 MW and also the capacity to produce 50 MIGPD of distilled water (MEW, 2016).

Al-Khairan IWPP is another project in the electricity plan that is expected to be in service starting 2021 for the first stage. The project involves harnessing conventional thermal power and is implemented in three stages with each stage expected to install a capacity of 1500 MW of power. The first stage is expected to be completed in 2021 while the second stage is expected to be complete by 2030. Another plant expected in the near future is the Al-Nuwiseeb Thermal Power Project that is also implemented in three phases with the first stage expected to produce power capacity of 3000 MW and is to be in service by 2022 (MEW, 2016).

The country also has a number of RE smaller projects that are both on-going and planned. Of these is the Al-Abdaliyah Integrated Solar Combines Cycle (ISCC) which entails hybridization of solar thermal power plant with combined power plant. This projected is expected to yield 280 MW of total power capacity with 60 MW of these being derived from the solar energy and is expected to be service by 2019. Table 3.2 summarises the future power plants in Kuwait. Current future projects plan in Kuwait shows that although Kuwait is targeting to invest in RE, the majority of the projects are using conventional power plants methods.

**Table 3.2: Kuwait future power plants projects (MEW, 2016).**

<b>Project</b>	<b>Capacity</b>	<b>Start</b>	<b>End</b>	<b>Comment</b>
Alshagaya	2000 MW	2011	2030	Renewable Energy technologies First phase to produce 70 MW. To be completed in 2017
Stage 2 Sabiya	500 MW	2015	2017	
Az-Zour South Gas Turbine Cycle Plant (CCGT-3)	250 MW	2017	2019	
Al-Abdaliya Integrated Solar Combines Cycle (ISCC)	280 MW	2017	2019	Partly use Renewable Energy technology 60MW from solar energy
Stage 3 of Sabiya	750 MW	2017	2022	
Fifteen Location for PV for water reservoirs	385 MW	2017	2025	Renewable Energy technologies 2 locations each year
Al-Nawaiseeb Thermal Power Project	6000 MW	2019	2022	3000MW to be finished in 2022
Al-Kharian IWPP	4500 MW	2021	2030	1500MW to be finished in 2021

### 3.3 Scenarios Selection

In Kuwait, as illustrated in the literature review (chapter 2), there is high potential of economic and environmental benefits from applying large scale PV plants. Beside that the government of Kuwait is advancing a number of policies aimed at promoting implementation of RE, especially PV because of its most suitability for Kuwaiti conditions (MEW, 2016). As most of planed RE projects are using 2030 as a target year, electricity consumption and peak load for year 2030 need to be estimated in order to aid in establishing future energy mixes of conventional and PV power plants

Assuming population increase to remain at a constant rate of 3.1% and governments planned housing projects are completed as planned, the political arena remain the same regarding subsidies and conservation effort. (Wood & Alsayegh, 2014). Future Electricity is expected to rise, The maximum peak load is expected to rise at a rate of 6% from 2015 to 2020 and then drop to 3% by 2030. Overall, the peak load is 12810 MW in 2015 and expected to reach 21885MW by 2030 with energy consumption 122TWh including loss factor of 10% (Wood & Alsayegh, 2014).

To enable the comparison in terms environmental and monetary impact, nine specific scenarios were created to identify whether the current policy is appropriate for Kuwait governments (table 3.3).



**Table 3.3: Scenarios created in this research for year 2030.**

<b>Scenario</b>	<b>Description</b>	<b>Percentage of maximum peak load</b>	<b>PV Capacity</b>
<b>1</b>	No Renewables	0%	0
<b>2</b>	Phase 1 of Alshagaya	0.32%	70 MW
<b>3</b>	Phase 1 and 2 of Alshagaya	4.57%	1000 MW
<b>4</b>	Phase 1, 2 and 3 of Alshagaya	9.13%	2000 MW
<b>5</b>	Government target	15%	3282 MW
<b>6</b>	4000MW	18.2%	4000 MW
<b>7</b>	5000 MW	22.8%	5000 MW
<b>8</b>	6000 MW	27.4%	6000 MW
<b>9</b>	No new conventional power plants	30%	6536 MW

**Scenario 1:** is the baseline for this research established based on, and describe the emissions from which future power plants will be operating (including what could be avoided due to implementing renewable energy plants, i.e. no RE plants applied). To come up with the baseline, it is assumed that Kuwait will not have any renewable energy plants in 2030, i.e. it will use 0% of RE by 2030. It is also assumed that the power demand will emanate from residential, industrial, commercial and governmental needs. The residential need will include current and new housing projects, home usage among other things. It is also assumed that the power production will be subject to a loss of 10% due to production and transmission processes which equals in total 21885 MW in 2030 (Wood & Alsayegh, 2014). .

**Scenario 2:** Kuwait will complete 70 MW of PV equalling to phase 1 of Alshagaya project without proceeding to phase 2 and phase 3 which equals 0.32% of maximum peak load in 2030.

**Scenario 3:** Kuwait will complete 1000 MW of PV equalling capacity of phase 1 and phase 2 of Alshagaya project without continuing to phase 3, which equals 4.57% of maximum peak load in 2030.

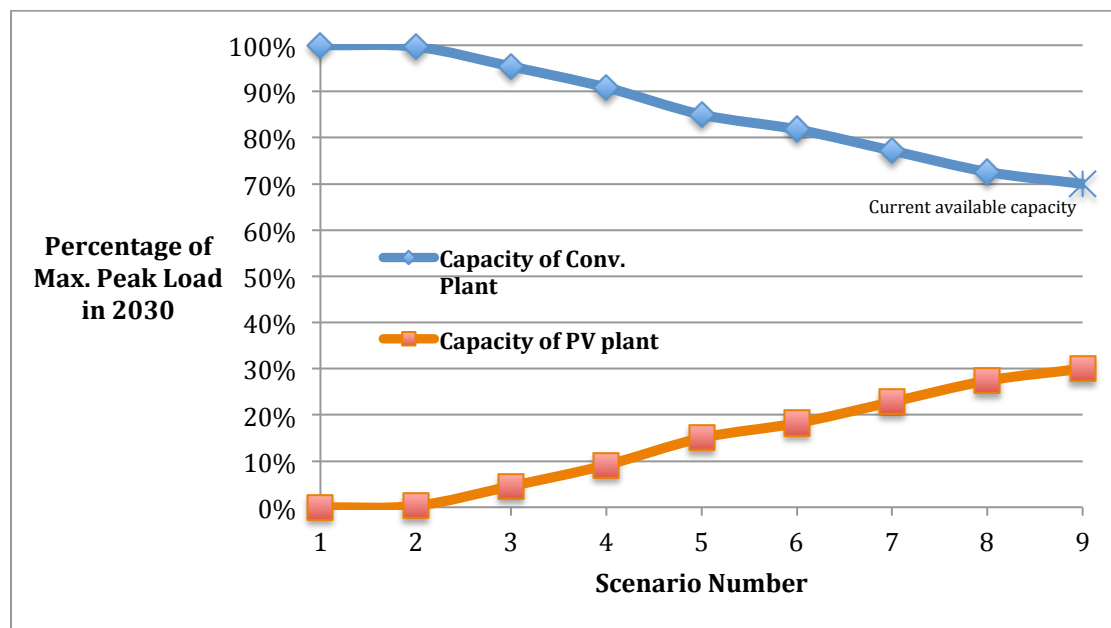
**Scenario 4:** In this scenario, Kuwait will adopt 2000MW of PV equalling the capacity of

the entire Alshagaya project.

**Scenario 5:** Government of Kuwait, as stated in literature, is targeting that it would achieve a 15% peak load from RE by 2030. With this in mind, this scenario will assume that PV accounts for 15% of maximum peak load in 2030, which equals to 3282 MW (15% of the expected 21885 MW).

**Scenarios 6, 7 and 8:** These scenarios will assume an increment of 1000 MW in every phase i.e. equal to 4000 MW, 5000 MW, and 6000 MW respectively. The purpose is to test and demonstrate the potential benefits of having increasing renewable energy power substituting the conventional power source.

**Scenario 9:** Scenario 9 represents the capacity that should be built to cover the need of maximum peak demand in year 2030 (none of the current power plants is substituted) equals to **6536** MW. I.e. no more conventional power plant will be built. Figure 3.6 shows the percentages of the peak load in 2030 covered by conventional and PV for the nine scenarios.



**Figure 3.6: Percentages of the peak load in 2030 covered by conventional and PV technologies for the nine scenarios.**

It is assumed that all energy from the PV sector is consumed. This is following the analysis by Wood & Alsayegh (2014), (Figure 3.7; 2008 figures). Given that PV only operates in daytime, it can be assumed that the lowest load in Kuwait while PV is operational is above 30% of maximum peak load (the maximum level of PV considered in scenarios created) and so load never dips below the level provided by PV.

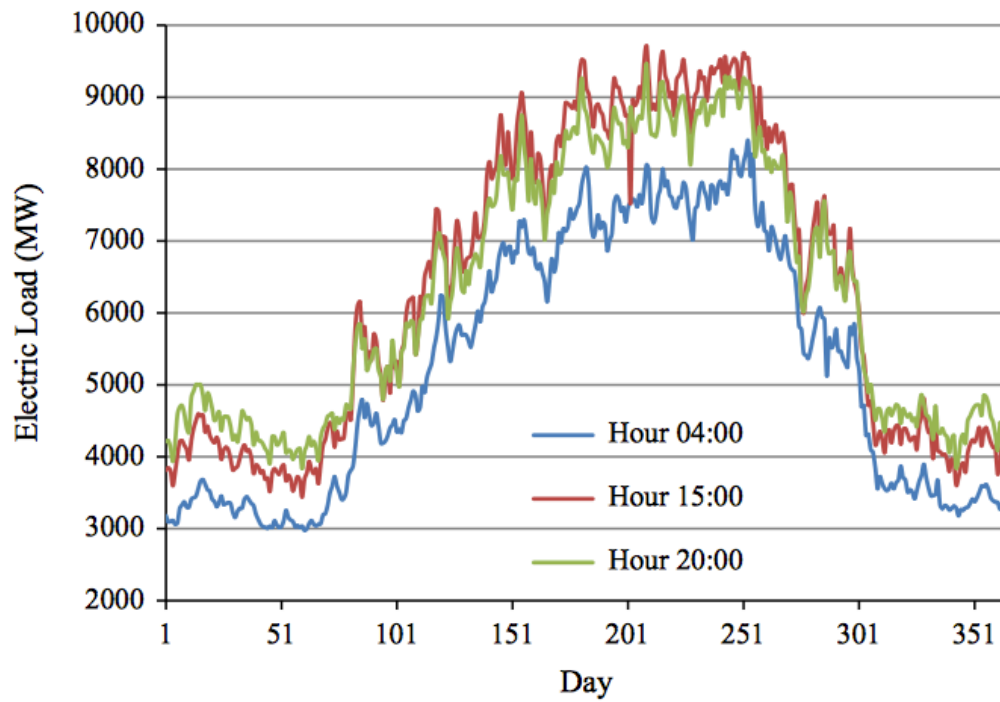


Figure 3.7: Typical load profile (2008 figures) at different hours of the day in Kuwait. Source: Wood & Alsayegh (2014).

Once PV gets to a certain level (percentage of maximum peak load), conventional energy sources are no longer sufficient to cover the nighttime peak. Thus batteries are introduced to provide extra energy at night (to cover the shortfall). This requires more PV to be installed to enable the batteries to be charged during the day as explained in section 7.1. In order to quantify the environmental and economic impacts of these scenarios to “value” and compare them, environmental and economic approaches and assessments are chosen and described in the next chapter.

### 3.4 Summary

In this chapter, Kuwait condition and energy policy are reviewed. It is found that Kuwait has high annual increasing rate in electricity approximately 6%. Moreover, there is a continuous need to increase the electrical plants capacity just to cover the high peak loads in summer (more than double the peak loads in winters). The expected future energy consumption and peak capacities have been reviewed based on the literature. Currently, the only main source of electricity in Kuwait is the conventional power plants and Kuwait government currently has plans to invest more in conventional plants. Based on this, future scenarios of energy mixes in Kuwait have been created. The scenarios represent different levels of deploying photovoltaic in the electricity grid to cover the maximum peak loads. The economic and environmental impacts will be assessed in this research.

## 4. METHODOLOGY

Environmental and economic approaches used to estimate the value of each of the scenarios created in the previous chapter are described in this chapter. After explaining the approaches, the major environmental impacts due to PV plants are described, as well as attributes that influence the economic impact.

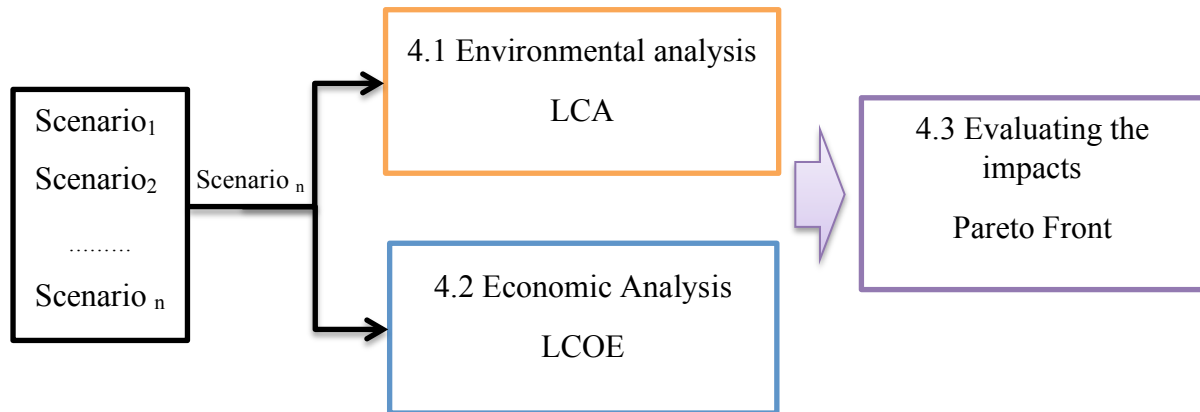


Figure 4.1: Methodology structure.

Using approaches described in this chapter, the environmental and economic impacts of each of the scenarios is estimated. Scenarios will be compared between each other environmentally and economically (Figure 4.1). If the impacts of the scenarios take different patterns (increasing PV reduce cost but increase certain emission) this may lead to multi-objective analysis. Pareto front will be used in this case in order to find the least negative overall impacts of the scenarios.

## **4.1 Environmental Analysis**

Researchers have explored the implementation of RE technologies in oil rich countries with respect to environmental issues, particularly using Life Cycle Assessment (LCA) approach (Jijakli et al., 2012; Dale, 2013; Aden et al., 2010; Environment Canada, 2012; Khan et al., 2005; Fleck & Hout, 2009; Oebels & Pacca, 2013; Ribeiro & Silva, 2010; Vandelight et al., 2012).

LCA determines what stage of the project has more negative environmental impacts; hence, consider the most appropriate approach to mitigate them (Dale, 2013). The assessment also assists in conservation of non-renewable resources (Agarwal et al., 2012). The purpose of using such analysis is to identify appropriate pollution strategies, encourage recycling of materials and wastes. It is also a tool that can be used in reducing costs and also identify appropriate performance indicators (Agarwal et al., 2012).

It is worth noting that this process has been used by numerous researchers in the areas of renewable energies and PV plants who are not limited to Dale (2013), Fleck and Hout (2009), Jijakli et al. (2012), Aden, Marty and Muller (2010), Agarwal, Tanger and Linich (2012) and Gong and Wall (2014).

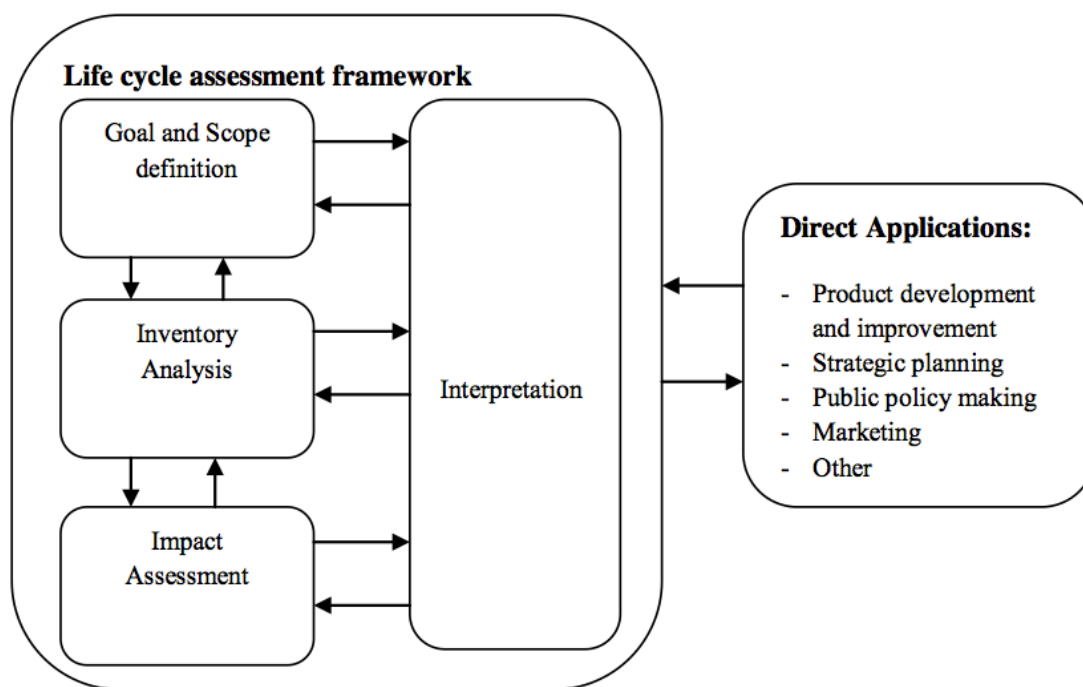
The importances of LCA is in determining environmental impacts of different power sources and scenarios, this will help in minimizing impacts by finding what stage has more impact and above all as a tool for helping decision makers in the comparison of different scenarios of PV.

### **4.1.1 Life Cycle Assessment (LCA)**

LCA is a systematic technique used to assess a project's processes from cradle to grave, assessing the impact of each phase has on the environment. It involves evaluating the environmental impacts for the entire life cycle of a product and/ or service (Gong & Wall, 2014; Home et al., 2009). That is, evaluating a product's impact on the environment from the time it is in raw material form to its disposal stage. As part of this research, life cycle assessment assists in estimating the environmental impact the proposed PV power plants will have.

In conducting LCA, midpoint and endpoint impacts are important factors to consider. Midpoint impacts are the links in the cause-effect chain and are said to happen prior to the endpoints. They are characterized by such factors like ozone depletion, smog creation potential and global warming potentials (UNEP, 2000). On the other hand, such things like

carcinogenicity, long-term climate change, human toxicity impacts and changes in biodiversity, acidification, ionizing radiation, eco-toxicity and land use among others characterize endpoint impacts (Hester & Harrison, 2010). The difference between the two is that the endpoint approach considers the environmental impacts at the end of the cause-effect chain, while the midpoint approach considers the impact earlier. The midpoint approach is more problem oriented, whilst the endpoint approach is a damage-oriented approach. Therefore, the midpoint approach is credited for translating impacts into environmental themes, whilst the endpoint translate the environmental themes into issues of concerns such as human toxicity, natural environment and natural resources (Hester & Harrison, 2010). In this research midpoint approach was utilized.



**Figure 4.2: Stages of an LCA (ISO, 2006a)**

Figure 4.2 depicts the stages followed while conducting an LCA assessment. From the model, it is clear that the first stage of an LCA is defining the scope and goals of the LCA, and then the data for the analysis is collected (inventory), and then an impact assessment is done to result the interpretation. These stages are explained below.

### **Goal and Scope definition**

To conduct any LCA, the first step entails clear definition of goal and scope. According to ISO 14040:2006, “the goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience”. In light to this, it is paramount for the LCA experts to state the expected results from the LCA exercise, how

those results will be and who will likely benefit from the results. Therefore, in summary, the goal forms the framework for the study by describing the product system in terms of its precincts, purpose and functional unit (FU).

### **Inventory Analysis**

The definition of goals and the scope of the LCA study is followed by the actual data collection and modelling, which is done under the life cycle inventory (LCI) phase of the LCA. The volume of data collected and analysed here is large and extensive and comprise that of raw materials and energy inputs to the product system and also that generated in the form of waste materials and effluents at each stage of the operation.

### **Impact Assessment**

It is in this stage that the inventory data collected and environmental impacts and attribute values of the plant are linked with the potential magnitude of these impacts. Here, the impacts are the direct consequences that are experienced in the environment due to the numerous emissions released from the plant.

### **Interpretation**

The final stage of an LCA is the interpretation stage. Here, the results are evaluated and a report detailing the findings is drafted. The findings aligns with the prescribed goals and scope of the study and are very essential in drawing the conclusions and recommendations.

#### **4.1.2 Environmental impact of PV power plant**

PV technologies have multiple environmental impacts; different Environmental Impacts of PV power plants will be described in this section. Any PV project life has some impacts on the environment that need to be addressed. Therefore, the major impacts of PV plants on such areas like water, land, soil, air and plants will be illustrated based on previous studies.

**Land Use:** Land is an important component in the installation of PV power plant. The amount of land required for the manufacturing phase of the PV in manufacturers and disposal phase are minimal compared with the land required during use phase. Land areas during installation depend on the scale of the PV plant. For smaller scale plants, which can comfortably be installed in rooftops of homes and commercial buildings, the impact on land use are almost negligible. On the contrary, commercially oriented PV plant (utility-scale PV) requires a sizeable land (Hernandez et al., 2015); hence, varied ways through which they impact land use. Environmental concern in respect to land use emanates, firstly, from the

location of the plant. The location, on its part depends on the technology employed, the topography, land use and the intensity of the solar resource. It is also influenced by factors like distance to power substations, transportation lines and urban centres, the climate and also the available finances for operations and maintenance (Fernandez-Jimenez et al., 2015). In respect to land use, PV power plants have some notable impacts that cannot be overlooked.

Some of the impacts on land use emanate from some hazardous materials that used during the manufacturing process of the PV cells and other components found in a PV power station. Chemicals like the hydrochloric acid, sulphuric acid, hydrogen fluoride, acetones and nitric acid may leak from the power plant. When this happens they affect the composition of the soil, thus affecting the flora and fauna of the area (Hernandez et al., 2014). Land allocated for the PV power plant are preferably set aside for this purpose; hence, such leakage would have no far-reaching impacts. In other cases, most of the PV plants are set in lands that are deemed low quality for other activities that would be directly or indirectly affected by the power plant.

The construction process requires land clearing, digging and alterations. Such activities alters drainage and water routes, loosen the soil; hence, exposing it to unwarranted erosion, increase in dust and affect the plant composition in the area. Nevertheless, despite these negative impacts, PV plants may have positive impacts on land use. The most notable is the maximum utilization of wasteland such as deserts that are not utilized in such activities like agriculture or residential areas (Belfiore et al., 2013). In addition, as reported in Altotratu Inc. (2011), PV plants have the potential to increase the Albedo (the fraction of shortwave radiation reflected from the Earth back into space), which leads to a cooling effect.

To maximize the benefits of a PV power plant by minimizing the negative use phase impacts on land use, the plant can be located in low quality areas and save the land that would be used for conventional plants. Such areas include deserts where no substantial activities takes place, abandoned mining land, brownfields and in existing transportation and transmission corridors.

**Water:** Unlike the fossil fuel plants that require supply of water for operation and maintenance, PV plants requires minimal amount of water supply during use phase approximately  $0.02 \text{ m}^3/\text{MWh}$  (Hernandez et al., 2014). The most essential element for PV plant is sufficient sunlight. Water in the PV plant is required to clean the reflective surface of the solar panels when dust covers them. Indeed, photovoltaic utility-scale stations have low levels of water consumption ( $0.02 \text{ m}^3/\text{MWh}$ ). Water pollution from PV would only come



from accidental discharge from the plant, and in most cases, when the plant is located near a water source. However, water needed in the manufacturing phase of the PV cannot be neglected. This is a concern of the exporting (manufacturing) country (Tsoutsos et al., 2005).

**GHG Emissions:** During electricity production, PV power plants do not emit any known GHG gases. Nevertheless, the manufacturing and disposal of the components will be responsible for considerable amounts of GHG emissions. This is because the two processes require the use of fossil fuel powered processes (Mason et al., 2006; Bergesent et al., 2014).

**Soil:** PV power plant only affect the soil during the construction stage and to some extent, during the disposal stage of the plant. During construction, the process of digging and clearing the available vegetation may have some impact on the soil exposing it to erosion. Similarly, there may be some leakages from some of the components such as oil spills from vehicles used in construction but at an almost negligible rate. During the disposal stage, if the components are not properly recycled, the toxic materials from these components may contaminate the soil. These impacts affect human global biochemical cycle, hydrological cycle, climate, and desertification (Altostratus Inc, 2011; Hernandez et al., 2014). PV plants are considered safe and these impacts are easily mitigated (Vandeligt et al., 2012).

**Air:** PV does not emit any GHG gas during working phase makes it attractive (Altostratus Inc, 2011). However, the challenges are the emissions during manufacturing and disposal stage (Hernandez et al., 2014).

**Human safety (physical):** Caution is necessary especially in the initial stages of setting up the plant. During ground clearing and material disposal, some pollutant like dust may find its way to the local environment and impact on human and animal (Turney & Fthenakis, 2011). Exposure to toxic materials from these plants would occur during manufacturing, decommissioning and waste material disposal. Inhalation of dusts like crystalline silica dusts and cadmium dusts exposes the person to diseases like silicosis and chronic obstructive pulmonary disease, which can be fatal (Rushton, 2007). Nevertheless, such instances are rare during the (use phase) implementation of a PV power plant project (Turney & Fthenakis, 2011). Employing recycling techniques of different materials and also ensuring that the plants are located relatively far from human settlements can reduce them. (Moskowitz & Fthenakis, 1990) (Tsoutsos et al., 2005).

**Noise Pollution:** During use phase, unlike other sources of energy that have significant noise pollution, PV power plants are not known to produce noise. As noted by Tsoutsos,

Frantzeskaki and Gekas (2005), even when the PV is located near residential places, it only produces small amount of noise if any during the day and no noise at night. This is because the system does not operate at night due to absence of sunlight that is key feature of this technology (Tsoutso et al., 2005).

**Ecosystem, flora and fauna:** The most notable time when PV power plant is known to affect the ecosystem, flora and fauna is during the initial stages of its construction. During this period, there are instances of vegetation clearing, soil disturbance and habitat destruction as the ground for the plant is being prepared (Beylot et al., 2011). Nevertheless, after completion, it has positive impact like offering shade, which is, in desert areas, beneficial on the microclimate around the plant and on the vegetation. Vegetation and small animals can also be allowed to return without major disturbance after the project is complete and operational. That is, especially in desert areas where temperatures are extreme, the animals and vegetation benefit from the shade obtained from the installed panels (Kammen et al., 2011; Beylot et al., 2011).

**Land surface temperature:** PV power plants are credited in improving the temperature conditions of the area the location of the plant. This comes as a result of the sufficient shades that originate from installed panels and reflectors. Similarly, the improved ecological situation of the area impacts on the precipitation cycle of the area (Hernandez et al., 2014), hence, in the long-run, decrease the temperatures. This happens due to the shade that is created by the installed solar panels. The shades prevent direct sunlight on the ground, hence, reduction in the amount of water that evaporates. Similarly, the reduced amount of water required in the plant ensures that only a little amount of water is used. A combination of all these factors ultimately leads to reduced temperatures in the area the plant is located. However, the effect of land surface temperature are minimal in the manufacturing and disposal stages (Masson et al., 2014).

**Human toxicity:** During the manufacturing stage of the PV panels and some other products that are used in the PV power plant such as inverters, some harmful materials are produced. For instance, during the manufacturing stage of the solar panels, toxic materials like the SO<sub>2</sub>, silicon dust and some acidic water among other harmful products are produced. Some of these products find their way either in the air, in the water or on the soil (Fu et al., 2014). In either of these, human beings are vulnerable and susceptible to illness and diseases associated with these harmful products. All the toxic materials are compounded, adjusted and presented as kg 1,4-dichlorobenzene equivalent (kg 1,4-DB<sub>eq</sub>) (Palanov, 2014). Nevertheless, in other

stages of the PV power plant, emission of toxic materials is highly reduced; hence, have little negative impacts on human beings (Summer & Radde, 2003).

**Terrestrial Acidification:** Acidification happens when a molecule receives a charged hydrogen ion  $H^+$ . It is worth noting that acidification depends on ability of the molecule to donate the hydrogen ions. In the case of PV power plants,  $SO_2$  is major source of acidification since it is the one produced in large quantities relative to other hydrogen ions donors. The acid produced reaches the earth mostly in the form of acid rain and has negative impacts on the flora and fauna and also toxic to human (Palanov, 2014). It is worth noting that these toxic materials are produced during the manufacturing stages of the solar panels; hence, when the power plant is already in operation, chances of their production are almost negligible.

## 4.2 Economic Impact

In order to estimate the economic impact of any power plant, Levelized Cost of Electricity (LCOE) is widely used. A number of researchers have considered the LCOE and the economic benefits of implementing different renewable energies in different countries, (Ghadge, 2012; Harder & Gibson, 2011; Hin & Zmeureanu, 2012; Zaytsev, 2014; SENER, 2013; Alsayegh & Fairouz, 2011; Hadi et al., 2013; Kegel et al., 2012). This is a common practice using LCOE when determining the economic impacts of RE technologies (Ghadge, 2012; Dale, 2013; Rushing et al., 2013; Campbell, 2008). It accounts for all the costs of a project from the start to end and is used to estimate their expected outputs. In this research US Dollar (\$) will be used as currency unit. Applying LCOE will give results that are comparable between scenarios and also other potential power resources.

LCOE is the electricity price that would bring a break-even between the lifetime cash flows and the economic lifetime of a power plant.  $LCOE = \text{Total Life Cycle Cost} / \text{Total Lifetime Energy Production}$ . Therefore, the sum of the present value of the LCOE multiplied by the energy generated should be equal to the net present value of costs (Said et al., 2015). The cash flows of the life of the plant (inflow and outflow) are defined in equations 4.1 and 4.2:

$$\text{Cash inflow for lifetime of the plant} = \sum_{t=1}^T E_t \times POE_t / (1 + r)^t$$

**Equation 4.1: Factors considered to calculate cash inflow (Said et al., 2015).**

Where  $T$  represents the life of the power plant,  $E_t$  is the annual energy production at year  $t$ ,  $POE_t$  is price of the energy at year  $t$  and  $r$  is the discount rate.

The time of the cash inflow starts from 1 since there is no electricity generation at the beginning of the plant (i.e.  $t=0$ )

$$\text{Cash outflow for lifetime of the plant} = \sum_{t=0}^T c_t / (1 + r)^t$$

**Equation 4.2: Factors considered to calculate cash outflow (Said et al., 2015).**

The time of the cash outflow starts from 0 to include initial costs and all annual cost of the project. Therefore, LCOE is determined by the point where the present value of the sum-discounted revenues is equivalent to the discounted value of the sum of the costs (equation 4.3).

$$LCOE = \left( \sum_{t=0}^T \frac{C_t}{(1+r)^t} / \sum_{t=1}^T \frac{E_t}{(1+r)^t} \right)$$

**Equation 4.3: Factors considered for estimating LCOE (Said et al., 2015).**

Where,  $C_t$  represents the net annual cost of the project. Such costs may comprise of factors such as the initial costs (I), cost of equipment, operation ( $O_t$ ) & maintenance ( $M_t$ ) cost and other fixed costs incurred even at the beginning of the project ( $F_t$ ). Therefore annual cost equation is represented in equation 4.4.

$$C_t = I + O_t + M_t + F_t$$

**Equation 4.4: Factors considered for estimating annual cost.**

Therefore, Levelized cost of electricity can be presented in equation 4.5:

$$LCOE = \left( \sum_{t=0}^T \frac{I + O_t + M_t + F_t}{(1+r)^t} / \sum_{t=1}^T \frac{E_t}{(1+r)^t} \right)$$

**Equation 4.5: Factors considered for estimating LCOE (Said et al., 2015).**

To calculate the cost, first the physical characteristics of the plant, and second, factors which may affect the monetary aspects are considered.

#### **4.2.1 Physical Characteristic of PV plant**

In terms of PV energy generation, parameters such as the location of the power plant, the solar resource (irradiation), local climate and the azimuth angle among others influence the plant performance. Azimuth angle is the compass direction, which the sun is coming from (Haag, 2008), measured clockwise around the observer's horizon from north (Bunyan & Ali, 2015). It can also be defined as the angle measured between true north and the position of the sun at a given time (Gouws & Lukhwareni, 2012). A suitable site should be flat and facing south if it is in the northern hemisphere and northern facing if in the southern hemisphere to maximize solar radiation (Al Otaibi & Al Jandal, 2011; Khan & Rathi, 2014). The site should also be positioned to avoid such things as high winds, flooding, extreme temperatures, seismic risks, inter-row shading, winds and land use activities that may affect or interfere with the performance of the PV plant. Another major factor related to site location is the annual and inter-annual variation in the global horizontal irradiation. All these factors have a direct or indirect effect on the quantity and efficiency of the power plant (Al Otaibi & Al Jandal, 2011; Dinçer & Meral, 2010). Besides affecting the daily power generation, they also have some effects on the total cost of the project and on the environmental sustainability (Hernandez et al., 2014; Turney & Fthenakis, 2011).

The capacity factor of the plant is also an important factor to consider. The capacity factor is the ratio of actual output to peak power that a power plant can deliver in a given period assuming is operating at full capacity. The capacity factor influenced by parameters such as the effect of weather, azimuth angle and orientation of the solar panel on power generation. It would also encompass the effect of photovoltaic efficiencies of the solar modules and solar irradiation among other things. Above all, the capacity factor used in determining the contribution of the power project in meeting the ever-increasing power demand. A higher capacity factor means that the plant is generating more power or is working more efficiently (Fraser, 2014).

Photovoltaic efficiency is a critical parameter when implementing the solar power project. The efficiency of the modules has a lasting impact on the project since it affects the ultimate daily energy generation. Nevertheless, as explained in Pure Energies (2014) article, high efficiency does not necessary mean better, but it is more about space optimization. According to them, the most efficient modules are smaller, so the required land for the project would be smaller compared to when less efficient photovoltaic solar modules are used (Environment Canada, 2012).

#### 4.1.2 Factors that influence monetary aspects

In respect to economic cost of the project, it is paramount to consider parameters such as the cost of the PV panels, the inflation rate, the prevailing discount rate, the interest rate, the escalation rate, the optimal contingency reserve and the expected export escalation rate (Branker et al., 2011; Lane & Rosewall, 2015; Zhang & Smith, 2008).

**The cost of the PV panels ( $I$ )** affects the decision on the type of the solar panels to be bought (Al Otaibi & Al Jandal, 2011; Silva et al., 2012) from the outset as well as in the longer term. In the longer term, it has a substantial impact on the annual cost of the project  $C_t$  and hence the LCOE.

**The discount rate  $r$**  affects the project in numerous ways but more specifically is its impact on the value of money and hence the LCOE. A higher discount rate would mean a higher LCOE, thus discrediting the economic benefit of a project. On the contrary, an attractive discount rate would be low with high energy output to have low LCOE. This would increase the expected economic benefit from the project (Branker et al., 2011; Zhang & Smith, 2008).

**Contingency:** is part of the initial cost ( $I$ ), to counter such adverse effects of such things like increasing inflation rate, uncertain interest rates, and discount rate, a contingency reserve fund is often created (Jackson, 2003). It serves as a caution against such eventualities that have the tendency of affecting the estimated cost of the project. With a substantial and optimal contingency reserve, the project cost is less prone to uncertainties. Contingency is used to compensate for the uncertainty of methods, inadequacies of scope definition and unidentified risks (Jackson, 2003). The initial cost estimated includes cost predicted plus the contingency

**Interest rate:** the interest rate is the discount rate ( $r$ ) that is applied for funding projects. Therefore, affects the annual instalment ( $F_t$ ). It is worth noting that most large projects that are capital intensive rely on financial institutions for funding. Indeed, the loans from these institutions are time bound. Thus, the annual cost  $C_t$  is higher (Lane & Rosewall, 2015; Branker et al., 2011). When interest rate increase the cost of the project increase; hence, more funds are required to complete it. In the long-term, the return on investment becomes low. In PV projects, high interest rate will result in high LCOE.

### **Indirect affects**

**Inflation rate** indirectly affects PV project, the inflation rate is associated with the price of the materials pertinent to the project and hence the annual cost of the project  $C_t$ . When the rate is higher, thus decreasing the value of money, the estimated cost of the project increases as the price of basic raw materials and services rise. When this happens, LCOE will be higher (Zhang & Smith, 2008).

**The escalation rate** in prices of basic materials impacts the overall cost of the project (I). When the escalation rate goes up, due to the effect of inflation and other extraordinary circumstances, the costs of basic materials goes up, hence, the annual cost  $C_t$  goes up. In the cost-benefits analysis, when the escalation rate is higher, the LCOE is higher. Escalation rates also affect such factors like wages, operation and maintenance costs (Chester & Hendrickson, 2005). When the escalation is higher, wages and other costs consequently go up making a project more expensive.

**Taxation** is another factor that has a direct impact on the annual cost of the project  $C_t$  and ultimately on the LCOE. Nevertheless, many governments are advancing tax incentives and tax reliefs to all renewable power generation plants (KPMG, 2011). Therefore, in the implementation of a solar power plant, the effect of taxation on cost does not have much effect, as incentives are available. Indeed, instead of taxations, renewable energy attracts compensation in form of carbon reduction credits.



### 4.3 Evaluating the Impacts

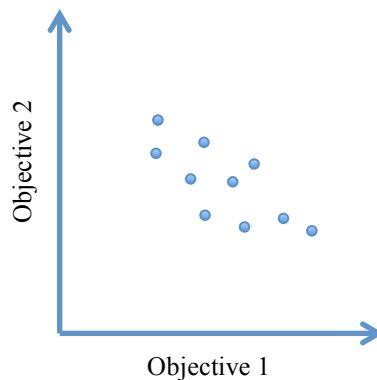
The economic and environmental impacts may take different patterns (for example, PV utilization decrease electricity cost but increase emissions) when applying different scenarios of PV percentages in Kuwait. In this case, in order to choose the optimal decision, Pareto Front method is used to solve this multi-objective optimization problem.

Pareto Front is an approach that is commonly employed for multi- objective optimization in engineering sectors to find the most efficient way of allocating resources (Pareto optimal) (hang et al., 2010; Capitanescu et al., 2015; *Kashani & Molaee, 2014*). In definition, Pareto Front is a set of actions, chosen as Pareto optimal when it is deemed impossible to improve one action without affecting or sacrificing at least another action. In this study, Pareto Front concept is utilized by ensuring normalization of objective functions and then combining the economic and environmental benefits objectives into one by assigning them weights. To normalize the two objectives equation 4.6 is used.

$$Z_i^{normalized} = \frac{Z_i - Z_i^{min}}{Z_i^{max} - Z_i^{min}}$$

**Equation 4.6: Normalization for Pareto graph (hang et al., 2010).**

Where  $Z_i^{normalized}$  represents the normalized objective for option  $i$  (in this case is the normalized emission for scenario  $i$ ).  $Z_i$  is objective quantity (emission),  $Z_i^{max}$  is the maximum objective quantity in range and  $Z_i^{min}$  is the minimum objective quantity in range where in this case is zero (i.e. no emission or cost).



**Figure 4.3: A geometrical illustration of normalized objectives.**

After doing this, it is possible to solve the resulting objective optimization function for all the possible weight combinations commonly known as the “Pareto front” or the “Pareto set”.

Based on the Pareto front concept, it is impossible to improve any point in the Pareto front on all dimensions simultaneously (Rout et al., 2014). While interpreting the Pareto front graph, the origin point is the utopian point, where in respect to this research, no costs are incurred and no CO<sub>2</sub> is emitted. Therefore, the point in this front, which is nearest to the origin is the “optimal point”.

#### **4.4 Summary**

In this chapter, the approaches that selected to assess the environmental and economic impacts for the scenarios were reviewed and selected. For the environmental analysis, Life Cycle Assessment has been described and the impacts that are relative to the photovoltaic power plants are reviewed. Second, the Levelized Cost of Electricity has been described to evaluate the economic impact and the factors related to photovoltaic plants that influence the LCOE are described. LCOE is the common approach used across the industry to assess the cost of generating electricity. Finally, to evaluate and find the optimal scenario the Pareto Front method is used to optimize the multi-objective problem. This was selected to demonstrate how such an analysis could be undertaken.

## **5. ENVIRONMENTAL ANALYSIS (LIFE CYCLE ASSESSMENT)**

In this chapter the research undertaken to estimate the environmental impacts associated with each of the scenarios using Life Cycle Assessment. The approach undertaken is described and the parameters that influence the environment, and those that arise as consequences of different environmental impacts are highlighted in chapter 4.

Different environmental impacts of PV power plants described in chapter 4, the impacts that will be taken in consideration in this research is described in this chapter. As mentioned in chapter 4, LCA is the methodology used in order to quantify the environmental impacts due to using each of the scenarios created, the project phases and considered factors is stated in this chapter. SimaPro software (PRé, 2016) is used as a tool applying LCA to calculate the impacts assessments in this research. In this chapter, scenario 4 (9.13% of maximum peak load by PV) will be used as an example applying LCA to calculate the environmental impact assessment.

### **5.1 Impacts to be focused on**

Adopting PV power plants have multiple environmental impacts as mentioned in chapter 4. However, this research will focus on climate change, terrestrial acidification and human toxicity since the rest of the impacts, though important to consider, do not have significant impacts in the area in question from Kuwaiti political prospective as explained below.

Climate change will be represented as the amount of CO<sub>2</sub> emitted in kg due to the use of each scenario. Terrestrial acidification, an environmental problem that, in its extreme, leads to decreased biodiversity and wildlife will be represented as the amount of SO<sub>2</sub> emitted in kg. In human toxicity, the toxic materials will be adjusted and presented as kg 1,4-dichlorobenzene equivalent. These impacts will give quantitative values of the effects of PV power plants on climate, biodiversity and wild life, and human. All of the three environmental impacts will be represented as per kWh units to be compared in the results. Table 5.1 gives a summary of the reasons for the selection of each impact.

**Table 5.1: Summary of environmental impacts of the scenarios.**

<b>Environmental impact</b>		<b>Brief summary</b>	<b>Action taken in this research</b>
<b>1</b>	Climate change	Originates from GHG emissions. Mostly produced during the production stages of the solar panels and other components.	Considered in this research
<b>2</b>	Terrestrial acidification	Acid by-products released mostly during manufacturing stages of PV panels forms acid rain. The acid affects humans, animals, plants and buildings among others.	Considered in this research
<b>3</b>	Human toxicity	Originates from toxic material produced during manufacturing, transportation and disposal of products used in PV plants. Affects human. Its consideration important to this study since its impacts and those of other power generation methods can be compared	Considered in this research
<b>3</b>	Land use	Project area located in flat, desert area with minimum or no activities and no governmental plan to use the land. No major use phase impacts with minimal during manufacturing and disposal.	Not considered in this research
<b>4</b>	Water	There is a water impact during manufacturing, but minimal impact in the use phase.	Not considered in this research
<b>5</b>	Soil	Land is flat; no major reshaping required. Soil structure not affected. Negligible use phase impact.	Not considered in this research
<b>6</b>	Physical Human safety	Project located far from city or settlement hence no direct use phase impact on health during use phase	Not considered in this research
<b>7</b>	Noise	No noise and if any, plant to be located far from settlements. Negligible use phase impact.	Not considered in this research
<b>8</b>	Ecosystem, flora & fauna	Only very few species of plants and animals found in the desert ecosystem. No substantial use phase impact.	Not considered in this research

**Climate change** is an important issue worldwide, there are numerous calls to reduce all activities that contribute to it. Besides the increasing demand for electricity due to increasing population and consumption needs, the other reason that prompts economies to adopt alternative energies is the issue of emission (Bergesent et al., 2014). Of the major contributors to climate change is CO<sub>2</sub>, a primary GHG, which affects the ozone layer. In the case of this research, CO<sub>2</sub> largest amount is produced during the manufacturing of the PV panels and transportation of materials. The GHG comes about as substantial amount of fossil fuels, which are major emitters of such GHG gases such as CO<sub>2</sub> (Masson et al., 2014). In the scenarios pertinent to this research, different numbers of solar panels and other components will be required depending on the amount of electricity produced. This means that, in each scenario, a different amount of CO<sub>2</sub> is produced, as the number of solar panels are different, hence, influence climate differently. In addition, CO<sub>2</sub> consideration in this research is also important since it will be compared with the amount produced in conventional oil power plants; hence, demonstrate the advantages/disadvantages of PV power in CO<sub>2</sub> terms. Climate change is considered due to environmental drivers for Kuwait.

In respect to **terrestrial acidification**, the impacts of acid on the environment, anywhere cannot be overlooked. As discussed in chapter 4, the acidification comes about when charged hydrogen ion (H<sup>+</sup>) changes the pH of the receiving medium. In the case of environmental impact of PV in respect to acidification, SO<sub>2</sub> is the main culprit since it is highly produced than the rest of hydrogen donors. When the acid from this and other GHG gases combine with moisture in the atmosphere, they fall in the form of acid rain, which have detrimental impacts on plants and animals (Palanov, 2014). The rain also may affect the soil and buildings.

**Human toxicity** is another environment impact that will be considered in this research. During the manufacturing stage of the solar panels, toxic materials such as SO<sub>2</sub>, silicon dust and some acidic products among other harmful products are released in the environment as explained by Fu and colleagues (2014). Whether these products find their way in the air, water or in the soil, human beings are vulnerable and susceptible to illness and diseases associated with these harmful products. Some diseases such as the silicosis, and chronic obstructive pulmonary disease among others are related to some by-products produced during the manufacturing stages of solar panels. This impact is pertinent to this research since it affects people especially in the manufacturing stage. The impact is also worth considering since in

each of the scenario under investigation in this research, substantial amount of toxic products are expected to be produced during the entire lifecycle of the plant; hence, it is important to know how much is produced in each scenario. The results obtained in each scenario are also comparable with those of the conventional oil power plants; hence, help determine the worth of the project in affecting the human toxicity.

The impact of any project on **land use** is paramount. This is because such projects like utility PV power plants occupies sizeable areas of land that cannot be used for other purposes unless the life cycle of the project is finished. In addition to the land they occupy, some projects would affect the activities of lands near the project (Hernandez et al., 2015). In regard to the scenarios in this research in Kuwait, the impacts of the project on land use will be out of scope because the land is assumed located in a desert area, where negligible land use takes place. This is unlike many other PV installations in the rest of the world where land for PV is a main concern (Belfiore et al., 2013). This land is far from human settlement and there is no known current governmental plan to use the land.

Impact of projects on **water** bodies is also an important factor to consider as noted in chapter 4. In the case of these scenarios, Kuwait has no water bodies such as lakes and rivers except the gulf. I.e. no water body is near such that it would be affected if accidental discharge of toxic material happens (MEW, 2013). Therefore, in this research, the impact on water will be out of scope.

In regard to the impact on the **soil**, the project is located in a flat area with no major vegetation; therefore, chances of destroying the soil structure or destroying its composition are minimal since no major reshaping or digging is required (MEW, 2013). In light to this, this impact will be neglected in this research.

**Noise pollution:** Projects located near human settlement or areas with animals face numerous challenges and rejections. Nevertheless, the Alshagaya desert where the proposed project is to be built is suitable area since no one is around to be affected by the noise. Even more, PV power do not produce sounds that would be considered a nuisance even if they were located in habitable areas (Tsoutsos et al., 2005). Therefore, impact will not be given weight in this research.

During project life, some activities and by-products from power plants project are said to have negative impacts on **human and animal**. As noted above, Alshagaya desert is located far from human and animals hence, no direct health problem may be associated with the

project. Therefore, this impact on human and animal does not hold considerable weight in this research.

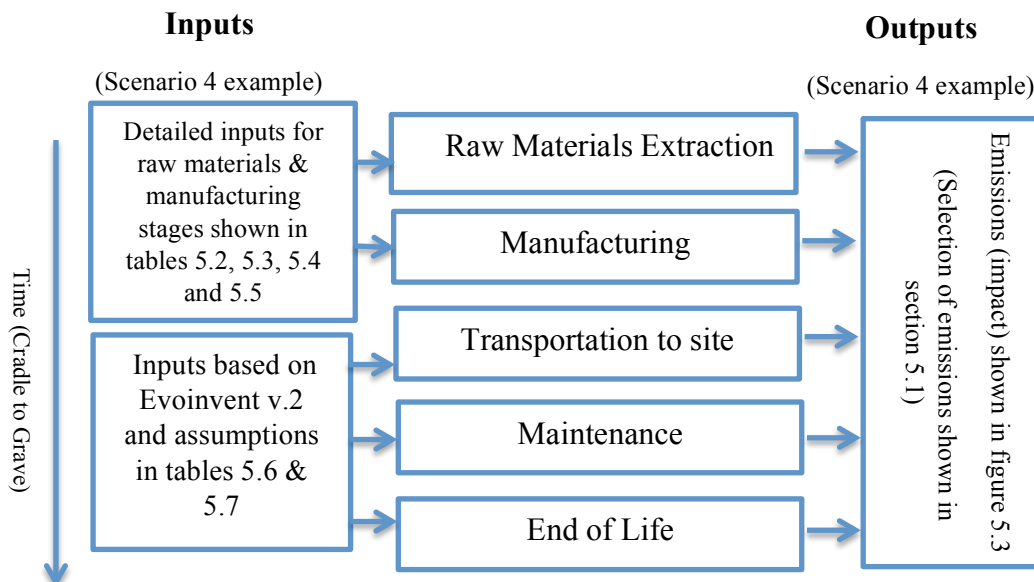
In respect to **ecosystem, flora and fauna** and their diversity, desert areas in Kuwait are known to have very little plants and animal species. A power plant of the nature under consideration in this research may affect large amount of animals and plants and their ecosystem. This happens majorly during the construction process (Beylot et al., 2011). Nevertheless, the location of this project does not inhabit any significant known plants or animals that will be affected. Therefore, this factor will also be neglected in this research.

## 5.2 Life Cycle Assessment

Analysis will involve the use of SimaPro software as a tool to apply LCA, however, any appropriate tool can be used such as GaBi (PE-international 2012). SimaPro is an LCA simulating software package that allows the modelling and analysis of life cycles of products based on ecoinvent v.2 (Frischknecht et al., 2005). Before starting the analysis, the power capacity for the scenario, goal and project phases of LCA will be set. In particular, the goal here entails calculating the environmental impact of applying the scenarios (scenario 4 is shown in detail). Activities involved in the project from extraction of raw material to the disposal stage of different materials used in the project are considered.

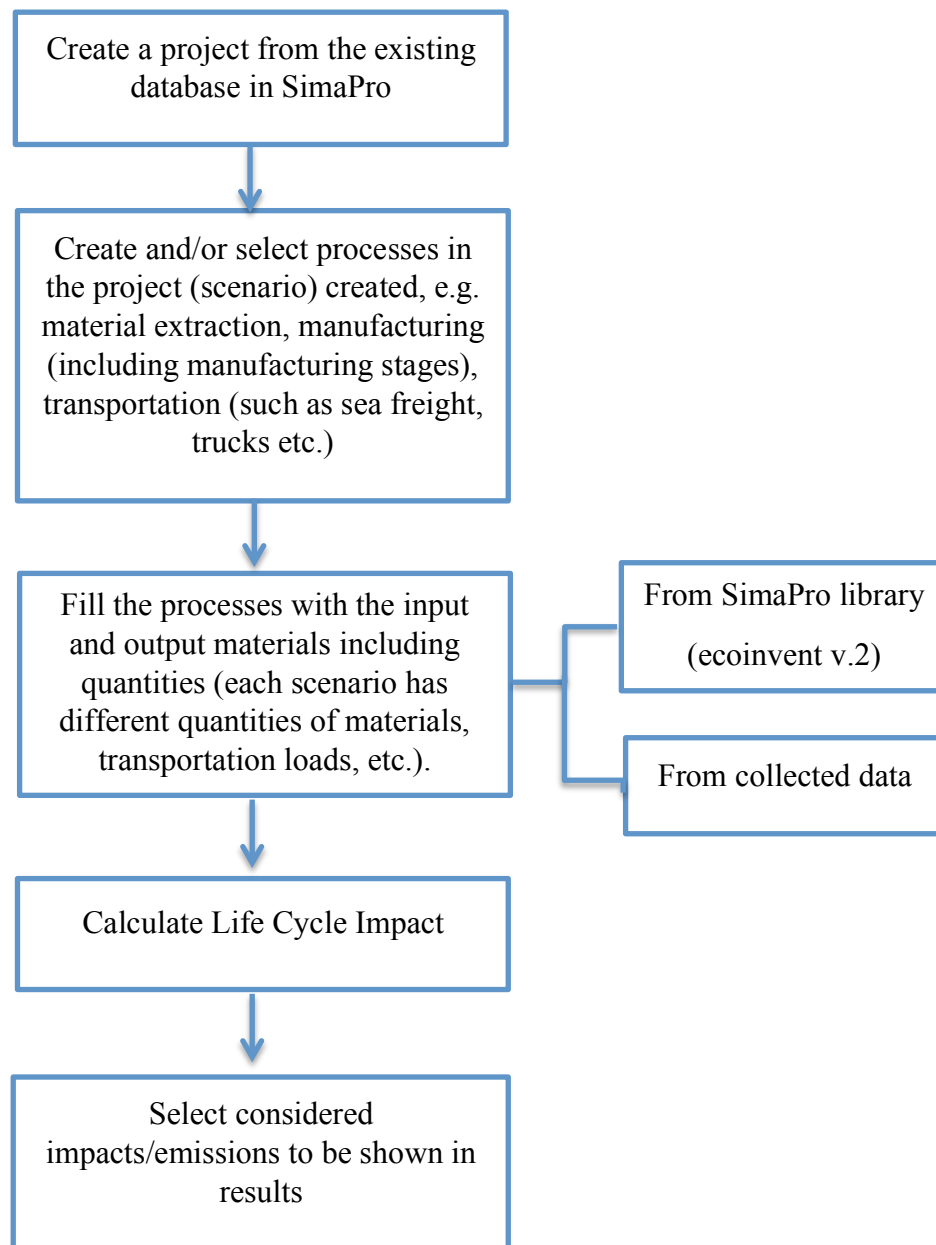
For comprehensive and effective use of SimaPro, a detailed input inventory needed to be supplied from reliable sources such as the actual manufacturer data and other peer reviewed secondary sources. Such details are added in SimaPro software to enrich its already in-built database. The database provides different types of inverters that are used in PV plants. Other information that will be entered includes transportation distance, truck capacity, and quantity of load transported.

For the LCA, the lifecycle of the PV projects involving stages of the product's life starting from the extraction of raw materials, manufacturing, transporting to the site, project life maintenance to end of life were considered. Figure 5.1a shows the stages considered in undertaking LCA, main steps taken to use SimaPro software are shown in figure 5.1b.



**Figure 5.1a: Stages considered for the scenarios.**





**Figure 5.1b: Main steps for LCA using SimaPro software (PRé, 2016).**

Raw material extraction: will include the environmental impacts due to the extraction of all the materials used to manufacture the PV panels, batteries if needed and the inverters that will be used on operation.

Manufacturing: will include the environmental impacts due to the operations (materials used and energy) in all manufacturing stages of producing the PV panels, batteries if needed and the inverters.

Transporting and maintenance: will include the environmental impacts due to transporting the PV panels, batteries if needed and inverters from the manufacturer to the site including sea and land transport and the environmental impacts for all road trips will be used for maintenance.

End of life (waste): will include the environmental impacts due to landfilling the PV panels, batteries if needed and inverters after the end life of the project.

One of the reliable sources for the data is Kuwait Institute for Scientific Research (KISR), Information available from this source, including interviewing subject experts, helped in identifying the type and crucial technical specifications of PV panels and other components installed at the site. One of the crucial details is that the PV panels installed at the site are made from polycrystalline (multi-crystalline) materials and were manufactured in China and the end of life will be landfill. This information will be assumed for all the scenarios in this research. The assumption is based on KISR expectation and the fact that China is the largest exporter of solar cells in the world and it is assumed that all its manufacturing processes for the cells matches the international standards. The assumption is consistent with a study done on PV panels of a polycrystalline type manufactured in China (Fu et al., 2014). The study has all the manufacturing processes input details required for a SimaPro simulation.

After gathering all important data and details, the SimaPro will be simulated to get information on total emissions, total energy consumed and other impacts such as global warming experienced during the lifespan of the PV system described in the scenario in question. The resulting details will be presented graphically and a detail discussion will ensue based on the findings.

## PV Panels Manufacturing

As part on the inputs for SimaPro simulation (figure 5.1), the inventory input data for PV panels used the work by Fu and colleagues (2014), examining the LCA of polycrystalline PV systems in China. Table 5.2 show the main characteristics of the PV panel to be used in SimaPro inputs.

**Table 5.2: Main characteristics of the PV panels (Fu et al., 2014).**

Item	Description
PV cell type	Multi-Crystalline
Mass	16.8 kg
Frame	Aluminium Alloy
Front glass	Tempering Glass 3.2 mm
Ethylene Vinyl Acetate (EVA) film thickness	0.5 mm
Wafer thickness	200 $\mu\text{m}$ $\pm$ 20 $\mu\text{m}$
Module size	1482 x 992 x 35 mm
Output to be produced by single PV cell	1 kW

The data for the input inventory is split as per the different production stages that the PV system undergoes before there are ready for the market. In right to the production of PV modules, Stylos and Koroneos (2014) and Stoppato (2006) outlined the following production stages in table 5.3. This stages are set in SimaPro software, then the inventory data for each manufacturing stage are used.

**Table 5.3: Manufacturing stages of the PV panels (Stylos & Koroneos, 2014; Stoppato, 2006).**

	Stage	Summary
1	Metallurgical Silicon Smelting	Heating of Silica using quartz sand and standard charcoal to get Silicon
2	Solar Grade Multi-Si Purification	The metallurgical silicon obtained is purified and then, through casting, it is transformed into large chunks of multi- crystalline silicon (Multi-Si)
3	Wafer Slicing	Wafering process involves combine the chunks of multi-Si with material like glass, steel wire, acetic acid and others. The resulting wafer is then sliced into extremely thin pieces of multi-Si wafer
4	Cell Processing	The multi-Si wafer is combined with other materials to form the multi-Si Solar cells.
5	Modules Assembly	The cells are compressed between two ethylene vinyl acetate copolymer sheets. A transparent tempered glass sheet and Tedlar/Al/Tedlar sheet respectively are then used to cover the front and backside of the PV modules.

As part of the inputs used for simulation shown in figure 5.1. Table 5.4 outlines the different material inputs required in each stage of PV panels manufacturing process (Fu et al., 2014). The simulation results of a total of 2000K PV cells will be analysed to meet the installed system capacity of 2000 MW

**Table 5.4: Detailed materials inputs used in PV panels manufacturing per kW (Fu et al., 2014).**

Metallurgical Silicon Smelting		Solar grade multi-Si purification	
Quartz Sand	20.48 kg	Metallurgical Silicon (>99%)	6.08 kg
Standard Coal	45.4 kg	Calcium Oxide	6.52 kg
Ingot Casting		Hydrochloric Acid (30%)	2.93 kg
Solar grade multi-Si	5.52 kg	Hydrofluoric Acid (20%)	0.06 kg
Silicon Carbide	61.92 g	Hydrogen (>99.8%)	0.5 kg
Quartz Crucible	15.37 kg	Nitric Acid (35%)	0.22 kg
Argon	10.5 kg	Nitrogen Gaseous	71.16 kg
Hydrofluoric Acid (49%)	254.03 g	Silicon Tetrachloride (>99%)	8.29 kg
Compressed Air	18.76 m3	Sodium Hydroxide (20%)	4.81 kg
Sodium Hydroxide	46.88 g	Water	10,396.87 kg
Water	492.47 kg	Electricity	2287.25 MJ
Electricity	157.54 MJ	Steam	385.02 kg
Steam	7.6 kg	Cell Processing	
Wafer Slicing		Multi-Si Wafer	3.34 kg
Multi-Si Ingot	5.47 kg	Ammonia	88.1 g
Glass	2.47 kg	Ethanol (99.7%)	0.23 kg
Silicon Carbide	175.78 kg	Hydrochloric Acid (37%)	2.57 kg
Steel Wire	17.11 kg	Hydrofluoric Acid	0.78 kg
Acetic Acid	0.6 kg	Nitric Acid (70%)	1.43 kg
Detergent	2.23 kg	Nitrogen	7.62 kg
Compressed Air	29.05 m3	Phosphoric Acid (85%)	9.31 g
Water	528.63 kg	KOH (21%)	2.76 kg
Electricity	24.01 MJ	Silver	67.9 g
Modules Assembly		Aluminium	0.38 kg
Multi-Si Solar Cell	1.09 kW	Water	866.04 kg
Glass	63.26 kg	Natural Gas	0.59 kg
Aluminium	11.77 kg	Electricity	686.69 MJ
Polyethylene Terephthalate Part	3.27 kg	Steam	26.15 kg
Polyvinyl fluoride film (PVF)	3.27 kg		
Ethanol	56.97 g		
Ethylene Vinyl Acetate Copolymer	7.52 kg		
Isopropanol	17.67 g		
Water	118.04 kg		
Steam	16.22 kg		
Electricity	72 MJ		

## Inverters

As part of inputs used in simulation (figure 5.1), the available data for inverters (Frischknecht et al., 2005) have an estimated lifespan of 15 years; hence, in a project estimated to have a lifecycle of 25 years, they would require to be replaced at least once. In scenario 4 (2000 MW of PV capacity), 8000 inverters are required to be operating at any time during the project lifecycle. Tables 5.5a and 5.5b provide the inputs details of the inverters.

**Table 5.5a: Inverters main specifications for scenario 4 (Frischknecht et al., 2005).**

Scenario 4 capacity	2000 MW
Capacity of each inverter	500 kW
Total capacity	2000MW
Inverters life time	15 years
Inverters weight	3000 kg
Inverters installed	4000
Total number of the inverters installed during project life	8000

**Table 5.5b: Materials inputs used in inverters manufacturing for 500kW inverter (Frischknecht et al., 2005).**

Electricity, medium voltage	4577.8	kWh
Aluminium, production mix, cast alloy	131	kg
Copper	335	kg
Steel, electric, un- and low-alloyed	1438	kg
Polyethylene	22	kg
Alkyd paint, white, 60% in solvent	22	kg
Lubricating oil	881	kg
Glass fibre reinforced plastic, polyamide.	71	kg
Glass fibre, reinforced plastic, polyester resin	44	kg
Printed wiring board, through-hole	0.2246	m2
Connector, clamp connection	0.237	kg
Inductor, ring core choke type	0.351	kg
Integrated circuit, IC	0.028	kg
Diode, unspecified	0.047	kg
Capacitor, film, through-hole mounting	0.341	kg
Capacitor, electrolyte type, > 2cm height	0.256	kg
Capacitor, Tantalum-, through-hole mounting	0.023	kg
Resistor, metal film type, through-hole mounting	0.005	kg
Sheet rolling, steel	1438	kg
Injection moulding	71	kg
Wire drawing, copper	335	kg
Section bar extrusion, aluminium	131	kg
Corrugated board, mixed fibre, single wall	13.6	kg
Polystyrene foam slab	1.6	kg
Fleece, polyethylene	0.3	tkm
Transport, lorry >16ft, fleet average	296.29	tkm
Transport, freight, rail	1016.1	tkm
Transport, transoceanic freight ship	36.271	tkm

## Transportation

Analysis of transportation impacts on the environment is important since different modes of transportation are used and each contributes directly or indirectly in affecting the environment. In this research, the resulting impacts from vehicles used to transport materials by load and ships used in sea transportation were analysed using SimaPro. The input required here is in tkm unit, which is achieved by obtaining the product of quantity of load transported in turn and the distance covered in kilometre (Ports.com, 2017).

Sea transportation is considered here since it is assumed that both the solar panels and the inverters were transported from China to Kuwait by sea. As part of inputs used in simulation (figure 5.1), tables 5.6 and 5.7 depict the transportation data assumptions for sea and land transportation.

**Table 5.6: Sea freight assumptions for scenario 4 (Ports.com, 2017).**

Object	From	To	Distance	Transportation Total Load	tkm
Solar Panels	Guangzhou , China	Shuwaikh port, Kuwait	12386 km	33600 Tons	416,175,648
Inverters	Guangzhou , China	Shuwaikh port, Kuwait	12386 km	24000 Tons	297.264,000

Sea freight is assumed to transport from Guangzhou port, China to Shuwaikh port, Kuwait 40 Tons capacity trucks are assumed to be used in transportations from port to installation area and 3.4 capacity trucks are used for maintenance. Maintenance trips are assumed to be two trips per month for 25 years (600 trips) (Mohamed & Hasan, 2012). Transportation Total Load is the total weight to be transported.

**Table 5.7: The inventory input for road transport (Ports.com, 2017).**

Object	From	To	Distance	Truck Capacity	Transportation Total Load	tkm
Solar Panels	Shuwaikh port, Kuwait	Alshagaya	111 km	40 Tons	33600Tons	3,729,648
Inverters	Shuwaikh port, Kuwait	Alshagaya	111 km	40 Tons	24000 Tons	2,664,000
Maintenance	Alshagaya	Jahra	70 km	3.4 Tons	Number of trips = 600	42000
End of Life (Landfill)	Alshagaya	Jahra	70 km	40 Tons	57,600	6,393,648

## Batteries specifications

Among the most common batteries employed in large PV power plants include the lithium ion (li-ion), the lead-acid batteries and the Sodium-sulfur batteries (IRENA, 2015). Using either of these batteries has their own advantages and disadvantages. In this research, the li-ion batteries were assumed because they are expected to be among the cheapest in the future with suitable energy capacity. This fact is well document in the IRENA (2015) report that shows that the price of li-ion batteries will be lower than that of other batteries (Figure 5.2). Therefore, as of 2030, with backing from previous literature and data (Kempener & Vivero, 2015; IRENA, 2015; Energy Matter, 2015; Stock et al., 2015), the research at hand considers li-ion batteries with a capacity of 120 Wh/ kg based on IRENA (2015) report and would cost \$ 200/ kWh by 2030 as reported by Kempener and Vivero (2015) and Nykvist and Nilsson (2015).

Li-ion battery were assumed to have a lifetime of 25 years compared to 15 years and 12 years for NaS and Lead-acid batteries respectively (Rudolf & Papastergiou, 2013). This property makes it more convenient for scenario created since it would reduce running cost, especially those associated with replacement of some materials associated with utility PV plants like cleaning the PV cells, replacing inverter units and AC subsystems (Lo, 2014). These batteries are also credited for their high energy and power density compared to their competing counterparts. Lithium-ion batteries is chosen because of their competitive prices, which is a fundamental principle to lower to LCOE and maximize the benefits. Table 5.8 summarizes batteries assumed specifications used in case of scenarios with batteries.

**Table 5.8a: Batteries main specifications assumed (IRENA, 2015; Kempener & Vivero, 2015; Rudolf & Papastergiou, 2013).**

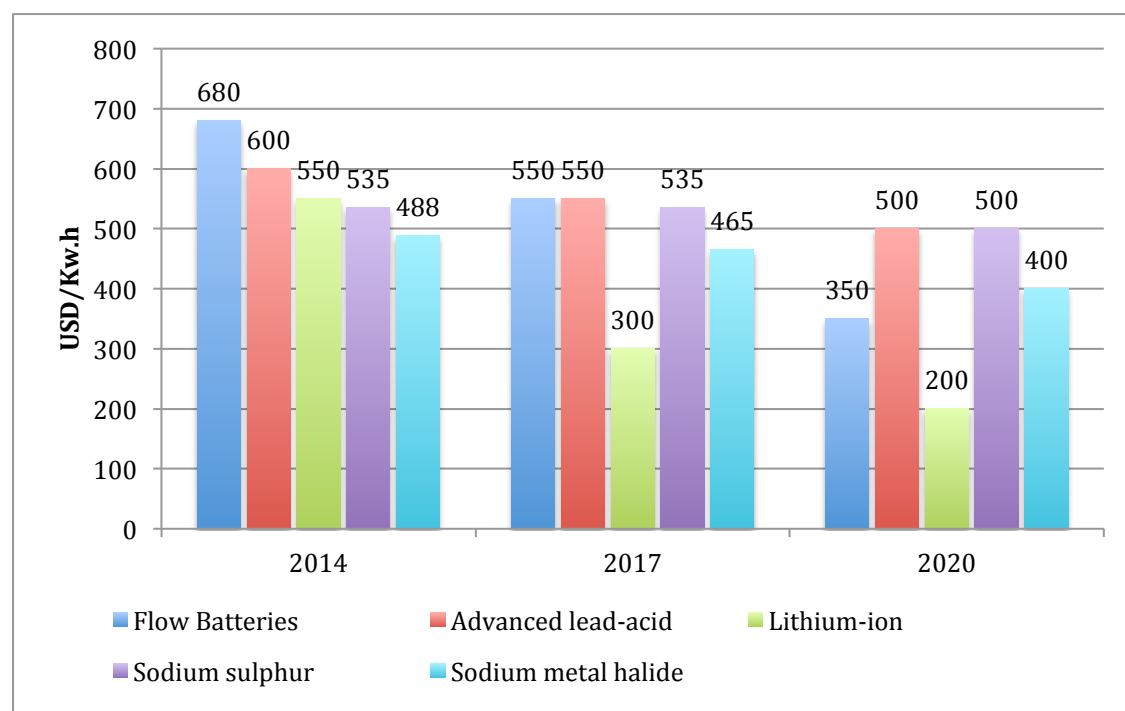
Batteries Type	Lithium-ion
Charge/Discharge efficiency	80%
Cycles	3000
Price	\$200/kWh
Batteries Life	25 years
Energy Density	120 Wh/ kg

**Table 5.8b: Detailed materials inputs used in batteries manufacturing per 1.8 kWh capacity (Frischknecht et al., 2005).**

Air	1.97	kg	Oxygen, in air	103	g
Aluminium, in ground	1.98	kg	Palladium, in ground	2440	pg
Artificial fertilizer	488	mg	Peroxides	23.7	g
Water	792	kg	Pesticides	42	mg
Baryte, in ground	3.22	g	Platinum, in ground	4.82	pg
Bauxite, in ground	4.75	kg	Sodium hydroxide	227	kg
Clay, bentonite	1.57	g	Rhenium, in ground	1390	pg
Biomass	6.49	g	Rhodium, in ground	2080	pg
Calcium fluoride	6.98	g	Sodium chloride	531	g
Chlorine	72.2	g	Sulfur containing material	987	mg
Chromium, in ground	899	g	Sand	6.48	mg
Clay, unspecified,	134	g	Molybdenum	26900	pg
Coal, 29.3 MJ/kg,	28.3	kg	Silicon, in ground	69.2	g
Cobalt, in ground	67100	pg	Silver, in ground	879000	ng
Complexing agent	43	mg	Silver, in ground	879000	ng
Copper, in ground	995	g	Sulfur dioxide	144	g
Oil, crude, 41 MJ/kg,	57.9	g	Sulfur dioxide, secondary	165	g
Oil, crude, 42.7 MJ /kg	21.1	kg	Sodium dichromate, in ground	53700	ng
Defoamer	163	mg	Steam from waste incineration	131	kj
Energy, unspecified	17.4	MJ	Sundries	36.1	g
Energy, from coal	4.78	MJ	Tin, in ground	489000	ng
Energy, from hydro power	59.4	MJ	Energy, unspecified	340	Mj
Energy, from gas	30.2	MJ	Uranium, 451 GJ per kg, in	142	g
Energy, from oil	26.1	MJ	Uranium ore, 1.11 GJ per kg, in	43.3	g
Energy, from uranium	120	MJ	Wood, unspecified, standing/kg	20	kg
Gas, oil production, in ground	14400	cm <sup>3</sup>	Wood, feedstock	257	g
Glue	53.7	g	Zeolite, in ground	18.2	mg
Sulphuric acid	248	g	Zinc, in ground	1.05	mg
Ink	189	g	Transformation, to urban,	24400	mm <sup>2</sup>
Insulation plates	935	mg	Transformation, to industrial	277000	mm <sup>2</sup>
Insulation stones	1.43	g	Occupation, urban, continuously	78100	mm <sup>2</sup>
Iron, in ground	5.43	kg	Occupation, arable	97200	mm <sup>2</sup>
Iron ore, in ground	4.62	g	Occupation, forest	1.12	mm <sup>2</sup>
Kaolinite, in ground	2370	g	Occupation, industrial area	10300	cm <sup>2</sup>
Lead, in ground	29.9	mg	Occupation, traffic area	154000	mm <sup>2</sup>
Coal, 10 MJ/kg,	1960	G	Occupation, unknown	1940	mm <sup>2</sup>
Limestone, in ground	1.31	kg	Forestry	7.1	mm <sup>2</sup>
Oil	2.06	g	Gas, natural, 30.3 MJ per kg, in	13.1	kg
Magnesium sulfate	259	mg	Gas, natural, 35 MJ/m3, in	52600	cm <sup>3</sup>
Manganese	34.6	g	Gas, natural, 36.6 MJ/m3,	1340	l
Manure	52.3	g	Nickel, in ground	4.26	kg
Marl, in ground	73.7	g	Methane	18.3	g



Lithium-ion prices were relatively high recently, but not higher than flow batteries and advanced lead-acid batteries (Poullikkas, 2013). Nevertheless, it is projected that, due to improvement in technology, their prices will continue going down, and a 120 Wh/kg battery would cost approximately \$200/ kWh by 2020 and the same price would be maintained beyond this value by 2030 since it is noted in the IRENA (2015) report that “Lithium-ion cells face a floor at the bottom of their cost curve due to material costs.” Figure 5.2 depicts the current and projected battery prices.



**Figure 5.2: Lowest current and projected utility-scale batteries price by type for utility-scale applications (IRENA, 2015).**

### Batteries assumptions

To show the impacts assessments for batteries (when required in the scenarios), 1 MWh batteries capacity assumptions is shown with estimated lifespan of 25 years; hence, in a project estimated to have a 3000 cycles and will only work at summer high peak times (when conventional power is not sufficient for the high peaks at night), given that even in scenario 9, batteries are only needed for about 120 days pa therefore they would not be required to be replaced. It is also assumed that the specific energy (kWh/kg) of the batteries is linear (IRENA, 2015). Table 5.9 provide the assumption made for 1 MWh of batteries.

**Table 5.9: Assumptions for 1 MWh of Batteries.**

Battery Type	Lithium ion Battery
Capacity of unit	0.12 kWh/kg
Weight of batteries to produce 1 kWh	8.33 kg
Weight of batteries to produce 1 MWh	8.33 ton

The resulting impacts from vehicles used to transport materials by load and ships used in sea transportation were analysed using SimaPro. The input required here is in tkm unit, which is achieved by obtaining the product of quantity of load transported in turn and the distance covered in kilometre (Ports.com, 2017).

Sea transportation is considered here since it is assumed that both the solar panels and the inverters were transported from Guangzhou, China to Alshagaya, Kuwait by sea. Tables 5.10 and 5.11 depict the transportation data for sea and land transportation.

**Table 5.10: Sea transportation assumption for 1MWh of batteries. (Ports.com, 2017).**

Object	From	To	Distance	Transportation Total Load	tkm
Batteries	Guangzhou port, China	Shuwaikh port, Kuwait	11595 km	8.33 Tons	96624.6
Batteries	Shuwaikh port, Kuwait	Alshagaya, Kuwait	111 km	8.33 Tons	924.99

**Table 5.11: Road transportation assumption for 1MWh of batteries (Ports.com, 2017).**

Object	From	To	Distance	Truck Capacity	Transportation Total Load	tkm
Road transportation	Shuwaikh port, Kuwait	Alshagaya	111 km	40 Tons	8.33 Tons	925
Maintenance	Alshagaya	Jahra	70 km	3.4 Tons	Number of trips = 600	42000
End of life (Landfill)	Alshagaya	Jahra	70 km	40 Tons	8.33 Tons	583

### 5.3 Impact Assessment

As part of the output on SimaPro simulation (figure 5.1), figure 5.3 shows the impact assessment (emissions) of scenario 4 (interpretation). Where it represents the total mass of the emissions divided by the expected energy production (122 TWh as assumed in section 3.3).

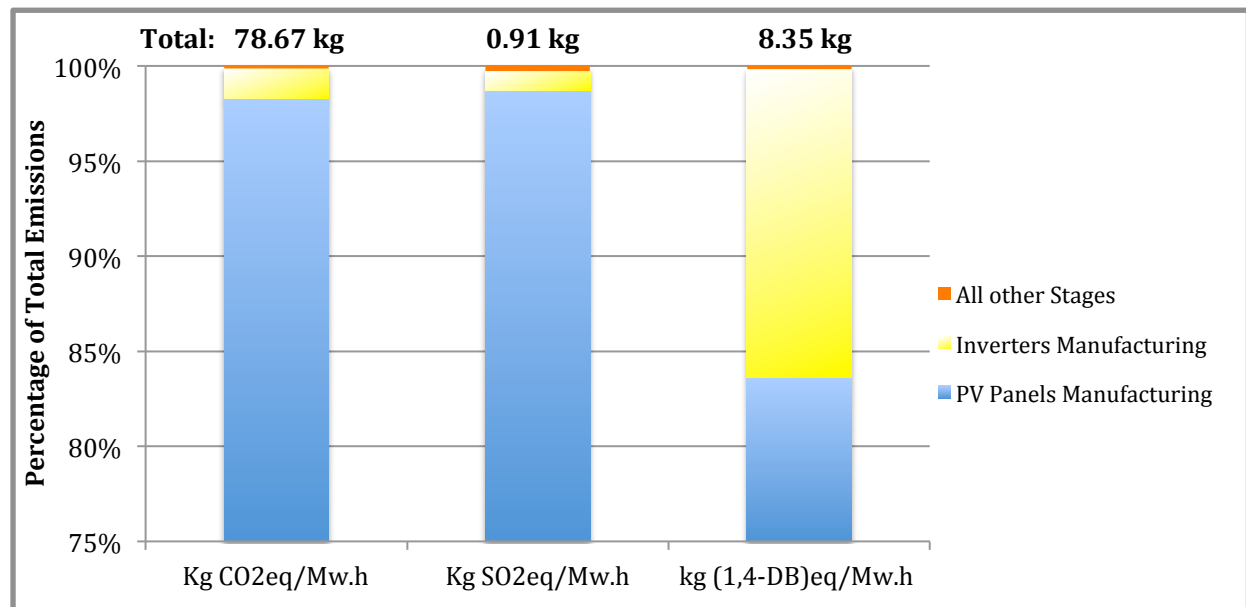


Figure 5.3: LCA results of scenario 4 (y-axis starts from 75%).

The results in figure 5.3 show that for scenario 4 (no batteries required) the manufacturing phase is the major contributor of all of the emissions in the PV plants Life.

In scenarios when storage is needed, the same methodology (in figure 5.1) is applied but including batteries with their inventory input in the simulation. The output results show (figure 5.4) that the manufacturing stage of the batteries is the biggest contributor of the emissions. I.e. the main emission source applying the scenarios is due to the manufacturing phase.

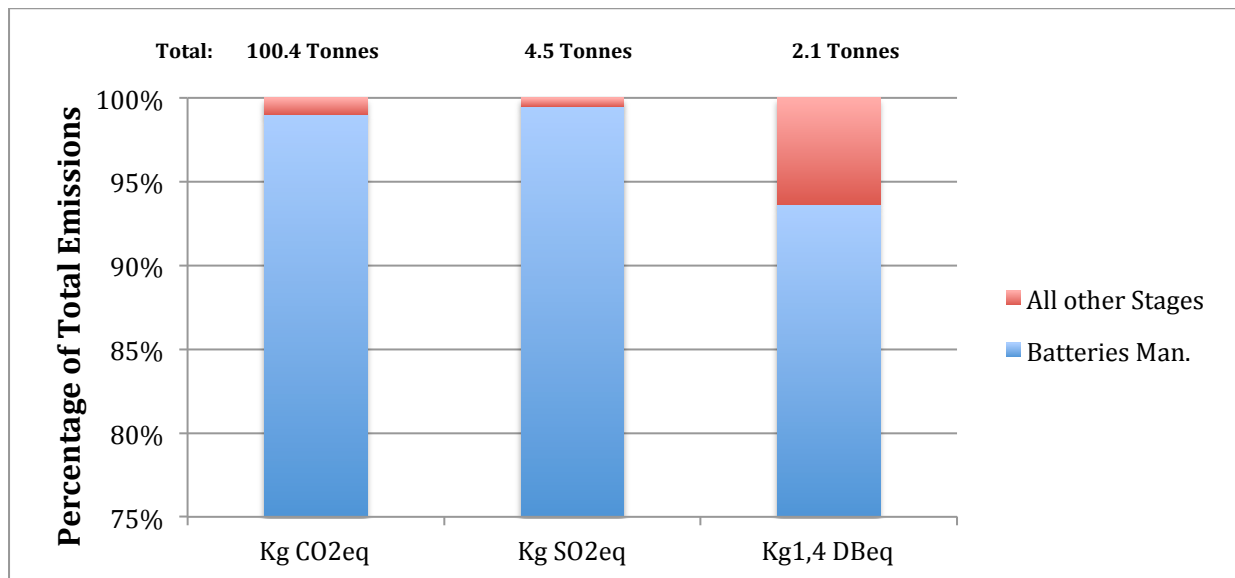


Figure 5.4: LCA result for batteries with capacities of 1 MWh (y-axis starts from 75%).

## 5.4 Summary

This chapter focused on the environmental analysis methodology, first, the impacts to be focused on are described. The valuing of the environmental impacts of the scenarios will be based on these impacts selected; climate change (CO<sub>2</sub>), terrestrial acidification (SO<sub>2</sub>) and human toxicity (1,4 DB). The LCA application is described in detail using SimaPro software as a tool and using scenario 4 (2000 MW) as an example, including input assumptions and output description. Moreover, batteries assumptions are reviewed and described. Finally, the impact assessment (results) for scenario 4 is described. The impact assessment of 1 MWh capacity of batteries is shown as example of batteries impact since scenario 4 does not include storage.

## 6 ECONOMIC ANALYSIS (LEVELIZED COST OF ELECTRICITY)

The purpose of this chapter is to calculate the monetary costs associated with each of the nine scenarios. The model created will help achieve estimates of the cost of the electricity produced when applying the different scenarios.

In order to calculate LCOE, despite the fact that there are numerous parameters related to PV plants, only parameters related to cost will be used in the analysis. They include; PV panels cost, contingency, discount rate, interest rate, escalation rate, inflation rate, parameters related to energy output (azimuth angle & location) and photovoltaic efficiency. The value and relevant information for each parameter is described in this section. The chapter also offers a justification for the reasons behind choosing assumed values for each parameter and highlights some of their implications on the project.

### 6.1 Description of the inputs:

**Cost of PV Panels (I):** This research work with \$1.3 a watt in 2030 as the cost of the PV that is assumed after reviewing the decline in prices of PV modules as reported by Feldman, et al., 2015. Based on the current available data, the cost of initiating a PV plant (utility scale) is dependent on the cost per watt of the PV. Data from such countries like US shows that the prices of modelled utility-scale PV systems are on the decline. For instance, the cost declined from \$2 per watt in 2013 and reached \$ 1.8 per watt in 2014 in the US. This decline is an equivalent of approximately 59% from what the cost was back in the year 2010 (Meza, 2014; Ramadhan et al., 2013). According to a document by IRENA, the prices in other markets like Germany, Italy, Spain and Portugal are also declining (IRENA, 2012). This research work with \$1.3 a watt in 2030 as the cost of the PV that is assumed after reviewing the decline in prices of PV modules as reported by Feldman, et al., 2015. The assumed price is also justified by the current report by Canadian Solar (one of the largest solar manufacturers) that indicated that its products cost (on the manufacturers) would continue falling by almost 25% from the current cost of \$47c/w to \$36c/watt in 2017. Despite the fall in cost to manufacture the PV, the company had increased revenue of almost 79% thus the price fall is sustainable (Canadian Solar, 2014). The price of \$1.3 thus, is estimated since it does not exaggerate the total price of the project, it is reflective of the trends in the price of the project and it also incorporates the installation and O&M cost of the PV. As explained in a report by NREL (2013), installation costs and O&M costs are on the decline due to technological advancement; hence,

the two are accommodated in the assumed price of the PV modules. Based on analysts' projections, the price of the PV will stabilize after 2020 and even beyond 2030 (Feldman et al., 2015), this price estimate is then justified. The expected reduction in prices of PV modules is demonstrated in figure 6.1 below that depict analysts' projections of the prices of PV modules up to 2040 (Feldman et al., 2015).

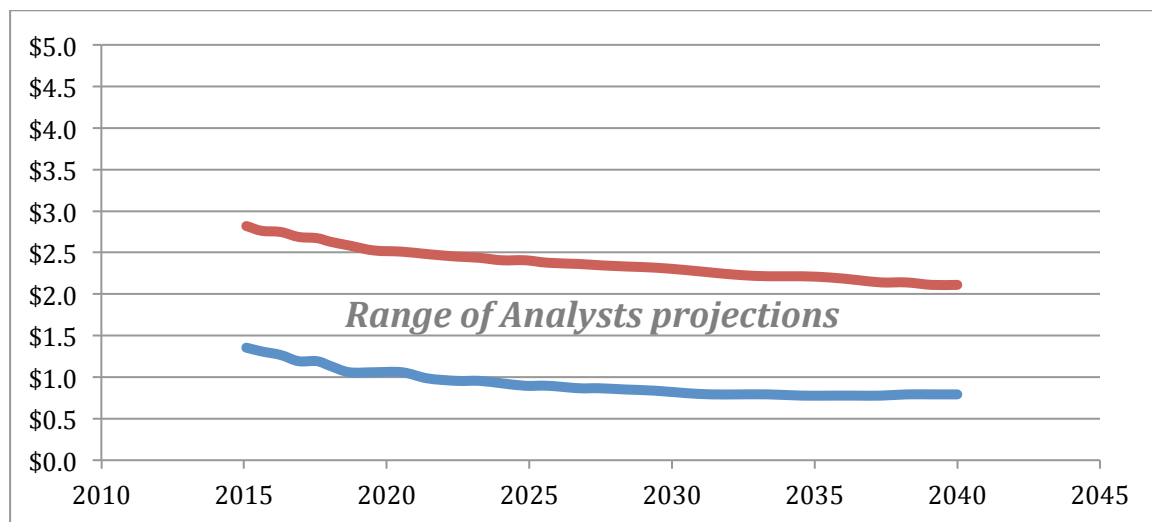


Figure 6.1: Analysts' projections of the prices of PV modules (utility scale) up to 2040 (Feldman et al., 2015).

**The photovoltaic efficiency is used to calculate energy output ( $E_t$ )** of 15% was chosen. The average efficiency of PV panels is between 11 and 20%. The type of PV system to be used in the scenarios is the c-Si system, which, according to the report by IRENA (2012) has specification suitable for Kuwait. The c-Si PV system also falls within the price limits (IRENA, 2012) assumed in this research. There are PVs panels with higher efficiencies than the efficiency selected here, but their prices are relatively higher.

**The contingency, is added to the (I)**, for this project will be set at 5%. This is deemed necessary since the project is relatively large, thus, would last for a considerable time before it is finally completed. During this period, noting the uncertainties in the world economy, some costs pertinent to this project may be adjusted upward, thus justifying the contingency fund. Some of the major issues that would warrant the contingency fund provision are such things as the changing world oil prices. In the recent past, the prices have been unstable and if they continue decreasing, the resultant effect would have a negative effect on Kuwait's economy, thus affecting the funding of the project. The fund would also caution against price fluctuations of different materials that would be required during the construction process. It would also caution against the projected inflation. Inflation affects prices of different

materials and has direct impact on operation and maintenance costs; hence, the contingency fund provision. All these factor notwithstanding, the fund is set at 5% based on experts and since it is expected that no major unforeseen costs will be incurred (NRCan, 2017). Similarly, as noted by Guzansky and Feldman (2015), Kuwait has a stable reserve fund that caution against drastic financial changes, especially those prompted by the looming uncertainties in the oil prices. Similarly, this project, being in line with the government initiative of turning to RE would receive much support from the government against major setbacks. This act is seen by the central bank's action of lowering the discount rate to encourage investors; especially those undertaking projects in the energy sector (Kuwait Foreign Investment Bureau, 2011).

**Currency inflation which indirectly affects ( $C_i$ )** has impact on the overall cost of any long-term project, especially because it is highly related to prices. In scenarios selected, the expected impact is critical and calls for sound estimation. This is true, especially noting that the project is significantly large; hence, will take time to complete. Material requirements for the project are spread across the entire period of the construction process. Inflation will affect the operation and maintenance cost of the project. To counter any future mishap related to overlooking the impact of inflation, this project will work with an inflation rate of 3.87 % which is a sound estimate given by a number of agencies (IEconomics, 2017; Trading Economics, 2015) which determines countries expected inflation rates shown in table 6.1. In this case, it is worth noting that the inflation rate will keep on changing, but as depicted in the above sources, not at such a greater margin; hence, the assumed 3.87% is deemed best for the project. Indeed, this rate is an assumed rate project to be maintained even beyond 2030. The percentage is also adopted having critically analysed the previous inflation as depicted in the diagram below sourced from IEconomics, 2017. In this research, the rate is also expected to remain this way noting Kuwait's Central Bank interventions aimed at encouraging investments in the country's economy. KD is not pegged on the volatile USD after the government decision in 2003 to shift its pegging from US dollar to undisclosed basket of currencies (Kuwait Foreign Investment Bureau, 2011). The inflation rate is also expected to remain within this range due to the consumer spending, lower food prices and also better performances by the country's commercial banks (Kanafani, 2015).

**Table 6.1: Forecast for Kuwait inflation rate (IEconomics, 2017).**

Kuwait	Q4/2017	2020	2050
Inflation rate (%)	3.4	3.87	3.87

**The discount rates ( $r$ )** can be taken as the governmental interest rate since it is a government project. The projected rate of 2% (Central Bank of Kuwait, 2012) will be used for the study with debt ratio 70% funding. The rate is adopted considering the positive, future, expected economic performance of the country, as predicted by Kuwait Foreign Investment Bureau (2011). The rate is not expected to waver, since it is under the watch of government agencies that are aiming for more investments in the country. Therefore, if the rate was to change, the most probable action is to move downward.

**Electricity export escalation rate:** Kuwait has experienced an increase in its population (Fattouh & Mahadeva, 2014). This increase has had numerous implications on different aspects of the economy such as increased demand for social amenities and mainly increasing demand for electricity (Ansari, 2013). For this reason, it is assumed that by 2030, Kuwait will not be exporting any electricity. And the subsidies will remain the same. Therefore, the escalation rate for this study is not a key parameter and will be considered to be 0%.

**Interest rate during construction ( $r$ ):** The current interest rate, as in 2017, in Kuwait is at 2% and is expected to remain constant during the construction period; 3% is added by local banks for short-term loans totalling 5% (IEconomics, 2017).

**The escalation**, which indirectly affects the annual cost ( $C_t$ ), rate for this project is set at 2%. This figure was assumed after considering the country's expected trends in inflation rate, interest rate and also the discount rate prescribed by the Central bank of Kuwait. Since the interest rate is expected to remain constant at 2% for the coming years, and the inflation rate expected to be 3.87% in 2030, it is assumed that the prices of components will escalate around 2%.

**The azimuth angle**, affects the energy output ( $E_t$ ), is  $180^0$  since Kuwait is located in the Northern Hemisphere; hence, the panels would be oriented south to face the equator so as to maximize the solar radiation.

**Location:** The Alshagaya site is an outdoor base station located approximately 70 km from, and almost the same latitude of, Kuwait international airport in Kuwait which is located on a flat surface desert ( $29.2267^0$  N,  $47.9800^0$  E) and will be connected to the national electricity grid. The area lies between ( $29^0$  N,  $47^0$  E) and ( $29^0$  N,  $46.5^0$  E) and at an elevation of between 50 m and 63 m above sea level. Solar radiation data for the Alshagaya is, however, not



available. The nearest location for weather data is Kuwait international airport, and at 63 meters above sea level. Kuwait international airport weather data can be used for this. Another reason for using this data from Kuwait International Airport, is the geographical similarity with the proposed the Alshagaya areas, it has an active station that record weather data (Al Otaibi & Al Jandal, 2011).

## 6.2 Levelized Cost of Electricity (LCOE)

The objective in this section is to simulate the PV system designed for scenario 4 (2000 MW). The electricity from the PV sector in the scenario assumes that all the electricity produced will be directly consumed by the national grid i.e. no storage. Table 6.2 shows a summary of the input parameters into RETScreen software (NRCan, 2017) for the energy simulation and LCOE calculations.

**Table 6.2: Summary of input parameters used in LCOE calculations.**

Input Parameter	Value	Remark
Cost of PV (I)	\$1.3 / W	This cost will be used, with acknowledgment of the expected decline on the cost of PV modules based on current studies (Feldman et al., 2015).
Contingences	5%	Assumed based on experts recommendations (NRCan, 2017).
Base case electricity system (baseline) Kuwait	Natural gas & crude oil	The country has been using natural gas and crude oil as source for all its power demands in Kuwait.
Kuwait inflation	3.87%	Despite variations in each year, this rate is expected to be the average rate expected in 2030 based on the current data and studies (IEconomics, 2017; Trading Economics, 2015).
Discount rate (r)	2%	This is the rate recommended by the Central bank of Kuwait (Central Bank of Kuwait, 2012).
Electricity export escalation rate	0%	All electricity produced is expected to be used locally because of electricity shortage, hence, no exports expected and no rise in cost.
Interest during construction	5% for 2 months	This is taken to coincide with the country's discount and the banks interest rate (Central Bank of Kuwait, 2012).
Photovoltaic efficiency	15%	Typical for the type of PV selected (IRENA, 2012).
Escalation rate	2%	This represents the projected future interest rate, discount rate and inflation rate of Kuwait
Location: Alshagaya Area	Kuwait International Airport	The area coincides with Kuwait international Airport (29° N, 47° E). It lies between (29° N, 46° E) and (29° N, 47° E)
Project life (T)	25 years	Typical for solar PV projects (IRENA, 2015)
Azimuth angle for Kuwait	180°	Kuwait is in the Northern Hemisphere; hence, the azimuth angle of 180

The solar resource data is important in to calculate the energy output from the PV panels  $E_t$ . The Alshagaya site is an outdoor base station located almost the same latitude of Kuwait international airport in Kuwait. The site is located on a flat surface desert and will be connected to the national electricity grid. The nearest location from the Alshagaya area having available weather and radiation data is Kuwait international airport (29° N, 47° E). Kuwait international airport weather data was, therefore, used for this study. Table 6.3 shows estimated solar radiation received on average during one day on a slope surface at the site. The slope is equal to the absolute value of the latitude of the site, which is 28° as was found out by Al Otaibi and Al Jandal (2011), who were doing similar research, and they used data obtained from the Kuwait International Airport. According to them, this slope in general maximizes the annual solar radiation in the plane of the solar PV.

**Table 6.3: Solar radiation data assumed for the Alshagaya area (NRCan, 2017).**

<b>Month</b>	<b>Daily Solar Radiation kWh/m2/day</b>
Jan	3.10
Feb	4.10
Mar	5.50
Apr	6.20
May	7.10
Jun	7.90
Jul	7.50
Aug	7.10
Sep	6.20
Oct	4.80
Nov	3.40
Dec	2.90
Annual Average	5.49

### 6.3 Summary of Results

In scenario 4 the installed power capacities for the PV sector is 2,000 MW (9.13% of max. peak load), a summary of the results for scenario 4 is shown in table 6.4 Assuming no storage of electricity from PV since it is connected to the grid and all the energy consumed instantly.

In scenario 4, the 2000 MW capacity of PV produce different amount of energy (MWh) every day during the year. This depends mainly on the PV specifications (section 5.2) and the daily solar irradiation for the geographic location; Kuwait (29.2° N; 48.0° E). Based on that, the total electricity (MWh) exported to the grid during the life of the project is calculated.

The total cost of the project (project life) are calculated taking in consideration all financial factors such as discount rate and income from electricity tariff. To have the electricity production cost from the PV, the total cost of the project is divided on the total energy produced (table 6.4).

**Table 6.4: Summary of the results for scenario 4.**

Power capacity of PV sector	2,000 MW
Average Annual Electricity exported to grid to load from PV sector	2,628,000 MWh
Electricity rate (Tariff)	7 \$/MWh
Electricity production cost from PV sector	53.3 \$/MWh
Energy production cost for scenario 4 (after combining with the conventional plants)	119 \$/MWh

The energy production cost from the PV sector in scenario 4 is 53.3 \$/MWh. This is the LCOE of PV sector. To have the LCOE for scenario 4, i.e. combining PV+ conventional, the total cost of both PV and conventional plants are divided on the total electricity produced. After combining, for scenario 4, the cost of electricity is 119 \$/MWh. In order to have the combined cost, the cost of the conventional plant has to be calculated.

### **Economic Analysis for Conventional Power Plants**

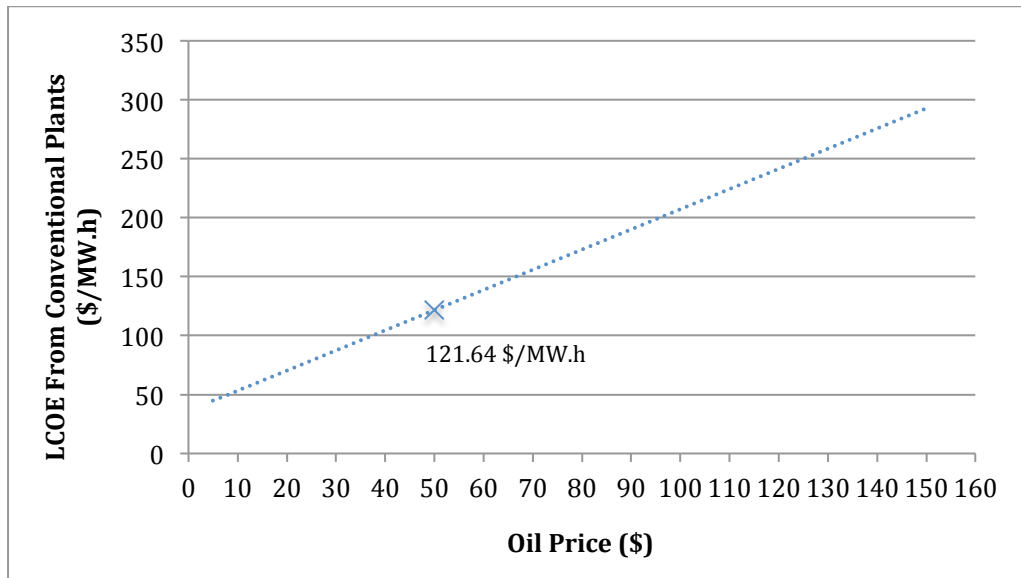
In the scenarios created, the energy mixes consist of percentages of PV plants and the second part is assumed to be from same current main energy source in Kuwait. A summary of the analysis of future conventional combined cycle power plants is shown.

In scenario 1, the baseline, the capacity of the conventional plants is assumed 6600 MW. The overnight cost, fixed operation & maintenance and the variable operation & maintenance assumption are shown in table 6.5. These factors are important to calculate the cost of electricity production. Moreover, fuel cost is included that is highly dependent on the plant heat rate and the energy contained in the fuel (oil). This will affect the total amount of fuel (oil) consumed to produce the energy, and hence total fuel cost. Assumptions are shown in table 6.5.

**Table 6.5: Calculations for Scenario 1 (baseline) that represent no PV installed (EIA, 2015; Black & Veatch, 2012; EIA, 2016).**

Plant Type	Combined Cycle power plant
Power capacity	6600MW
Annual Electricity exported to grid	68,261,365 MWh
Electricity export rate (tariff)	7 \$/MWh
Overnight Cost (\$/kW)	661.8
Total overnight Cost (\$)	4,367,880,000
Fixed O&M (\$/ kW/yr.)	6.22
Total fixed O&M (\$/yr.)	41,052,000
Variable O&M (\$/MWh)	19.34
Total annual Variable O&M (\$/yr.)	1,320,174,799
Heat Rate of the Plant	10044.054 Btu/kWh
Energy From Oil	5,867,946 Btu/Barrel
Oil Price (\$/Bbl.)	50
Total Energy Cost from Conventional Combined Cycle Plants (LCOE)	121.64 \$/MWh

All these factors are considered to calculate the total cost of energy production including income from electricity tariff. The total cost of the project is divided on the total electricity produced to have LCOE. The LCOE from conventional plants is 121.64 \$/MWh, however large part of the electricity cost from conventional power plants are dependent on fuel (oil) price. Economic results shown are based on 50 \$/Bbl. The calculations of different oil prices results different LCOE. The results of the calculation of LCOE of different oil prices are shown in figure 6.2.



**Figure 6.2: LCOE sensitivity of Conventional Power Plants based on Oil Prices.**

The change in electricity cost because of oil price may affect the decision of applying the PV scenarios. If LCOE of PV sector (in a scenario) is lower than the LCOE from conventional it will be economically favourable. However in the cases of different oil prices this may not hold. Detailed results and discussion will be in chapter 7.

## 6.4 Sensitivity analysis

To test the sensitivity for this scenario, sub-scenarios will be tested. Since the project is set (size and capacity of the panels, location) the initial cost of the project is normally known at the beginning of the project. During installation and life of the project some variables could change including the electricity tariff from Kuwait government (i.e. decreasing subsidies), the interest rate from Kuwait central bank and the inflation rate. Reasons why variables chosen are shown in Table 6.6

**Table 6.6: Inputs effects on sensitivity analysis.**

Input Parameter	Remark
Kuwait inflation rate	Based on the current data available for 2030 the estimated inflation rate is 3.87%. For the sensitivity, the maximum and minimum numbers will be used based on the maximum and minimum inflation rates in Kuwait based on the past 5 years which is 6% and 2% respectively (IEconomics, 2017)
Discount rate	2% is the discount rate projected for Central Bank of Kuwait for 2030. The minimum value for the sensitivity will be set at 0% assuming government will support the project. The maximum value is 5%, which is the maximum interest rate from local banks (2% + 3%)
Cost of PV	The capital cost of PV will be based on \$1.3 / W based on the current available studies. Because of the prices is expected to be stable on 2030.
PV efficiency	15% that coincides with the set cost for PV selected.
Contingences	The contingency percentage is set to 5% which is not affected since it is a strategy applied on the initial cost of the project
Electricity Tariff	Current electricity tariff is 2 Fills (since 1966 did not change). Currently there isn't any orientation from the government to increase the tariff, but in this sensitivity analysis the maximum will be set at 4 fills (100%) increment to test its effect assuming same policy taken when Kuwait increased petrol price (slightly higher than the recent increased petrol price by 83%). And the minimum will be stayed at 2 fills.
Electricity export escalation rate	All electricity produced is expected to be used locally, hence, no exports expected and no rise in cost (0%)
Interest during construction	This is taken to coincide with the country's discount and the banks interest rate which is 5% for 2 months, will not be changed since it is small period compared to life of the project
Fuel Escalation rate	2% is augur with the projected future interest rate, discount rate and inflation rate of Kuwait, this will not be changed since it does not affect the project cost (fuel is only used for the conventional power plants)
Project location	The location of the project is set in the Alshagaya area (desert) since all the governmental RE planned/oriented projects located there
Azimuth angle for Kuwait	Kuwait is in Northern Hemisphere; hence, the azimuth angle is 0 degree. So this is set depending on the location of the project

Table 6.7 shows a summary of inputs and results (output from RETScreen, 2017) from PV sector after sensitivity for scenario 4 as an example in sensitivity analysis.

**Table 6.7: Summary of inputs and results in the sub-scenarios**

<b>Sub-scenario</b>	<b>Electricity Tariff</b>	<b>Discount rate</b>	<b>Inflation rate</b>	<b>Energy production cost (\$/MWh)</b>
<b>More beneficial</b>	4 Fills (\$0.014) per kWh	0	2%	49.5
<b>Most likely</b>	2 Fills (\$0.007) per kWh	2%	3.87%.	53.3
<b>Less beneficial</b>	2 Fills (\$0.007) per kWh	5%	6%	53.43

From the results it can be noticed that the electricity tariff has the major effect on the energy production cost (LCOE). Having the two extremes (less beneficial/ more beneficial) values for each scenario will give better projection of the future scenarios. The results will be illustrated in chapter 7.

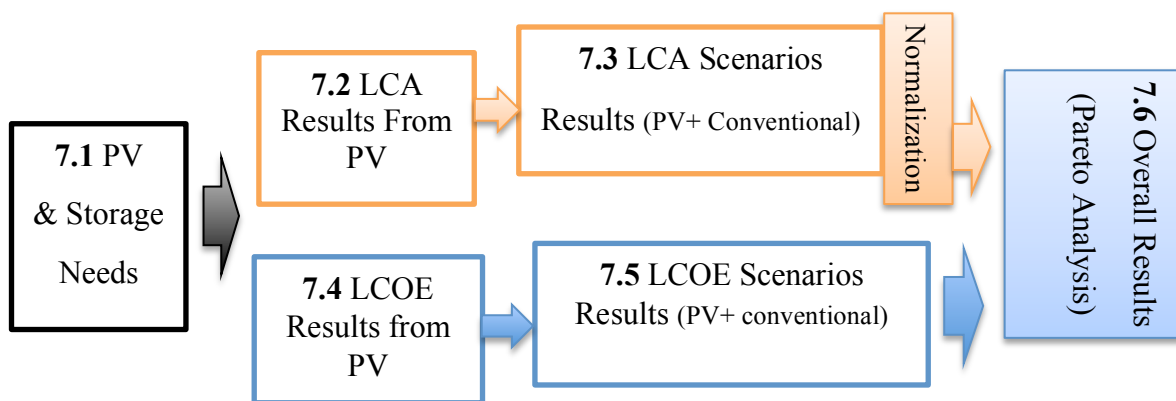
## 6.5 Summary

This chapter focused on the economic analysis methodology. First, the descriptions of the inputs and variables assumptions that influence the LCOE are described. These inputs are used in RETScreen software as a tool to calculate the LCOE. Scenario 4 (2000 MW) results are shown as an example of the methodology. Moreover, sensitivity analysis is done to show the more beneficial, most likely and less beneficial values for the scenarios.



## 7 RESULTS AND DISCUSSION

This chapter shows summarized findings and the analysis of applying Life Cycle Assessments (LCA) discussed in chapter 5 and Levelized Cost of Electricity (LCOE) discussed in chapter 6. First the discussion on the key findings from PV sector then followed by the combined conventional power plants source with PV sectors proposed in the scenarios, to help in undertaking overall conclusions.



**Figure 7.1: Structure of chapter 7.**

Figure 7.1 shows the structure of this chapter, the results are in three categories:

- Category 1: Measuring Environmental impact applying LCA: This involves quantifying the three impacts discussed in chapter 5 first for PV plants only and secondly for the scenarios (PVs+ Conventional combined).
- Category 2: Measuring the Economic Impact applying LCOE: This entails calculating the LCOE first for PV plants sector and secondly for the scenarios (PVs+ Conventional combined).
- Category 3: Combined LCA and LCOE: Overall view on the impacts results of the scenarios. Illustrating if different combination on the impacts is considered to value the scenarios may lead to multi-objective optimization solved using Pareto analysis to ascertain the scenario with the lowest impact.

## 7.1 PV and Storage Needs

Since the scenarios created are based on covering percentages of the maximum peak load, on peak load days. Also, the electricity produced from PVs is assumed to be consumed directly to the grid. At night, when the load decreases, the grid will depend on conventional power plants. However, once PV gets to a certain level of covering the peak load (after 13% of maximum peak load), conventional energy sources are no longer sufficient to cover the night-time peak. Thus batteries are introduced to provide extra energy at night to cover the shortfall. This requires that more PV to be installed to charge the batteries during the day. After 13% of maximum peak load batteries are required. Figure 7.2 shows comparison between scenario 4 and 6.

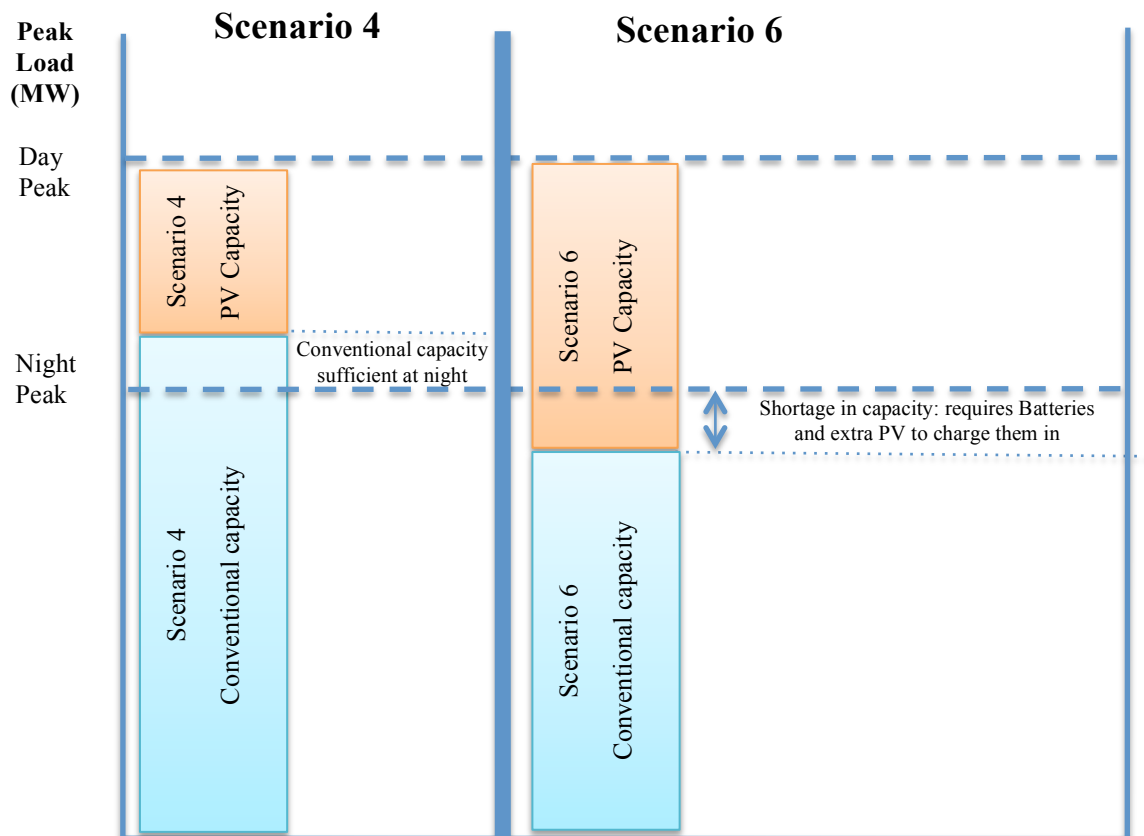


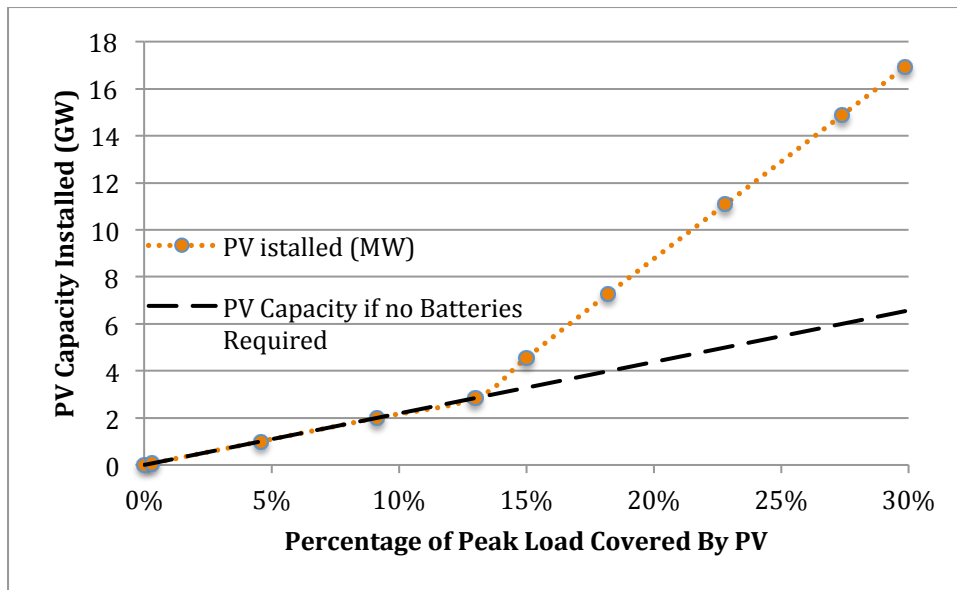
Figure 7.2: Conventional and PV capacities comparison between scenarios 4 and 6.

Table 7.1 shows the calculation for scenario 6 as an example. The calculations are based on the maximum peak night loads in the maximum peak load day in the year (upper bound).

**Table 7.1: Example calculation for battery usage in scenario 6.**

Parameter	Value	Comments
PV %	18.2%	Of maximum peak load
Load from PV	4000MW	
Max. peak load	21885MW	
Conventional capacity in scenario 6	17885MW	I.e. 21855 – 4000
Peak load at night	87%	(MEW, 2013)
Peak load at night	19051MW	87% * 21885
Shortfall	1166MW	19051-17885
Night time	11 hours	In August
Maximum battery storage needed	12826MWh	11 * 1166MW
Battery efficiency	80%	(Kempener & Vivero, 2015; IRENA, 2015; Energy Matter, 2015; Stock et al., 2015).
PV required	4.90 MWh/MWp	RETScreen software, Kuwait specific (NRCan, 2017)
PV required	3271MWp PV	12826 ÷ 4.90 ÷ 80%

This means that with the use of batteries the relationship between the amount of PV capacity **are not linear** with the percentages of the maximum peak load (because of the need of extra PVs to charge the batteries) as shown in figure 7.3.



**Figure 7.3: Difference in PV capacities with storage compared with the case if no storage is required.**

The need for additional PV due to using batteries will affect both LCA and LCOE results. This is particularly evident after combining the PV plants with the conventional sources (the overall impacts of the scenarios). Basically with more PV installed, more energy (MWh) is produced and less energy is required from conventional plants. Table 7.3 shows the energy produced from PV in the scenarios are not linear with the percentage of maximum peak load.

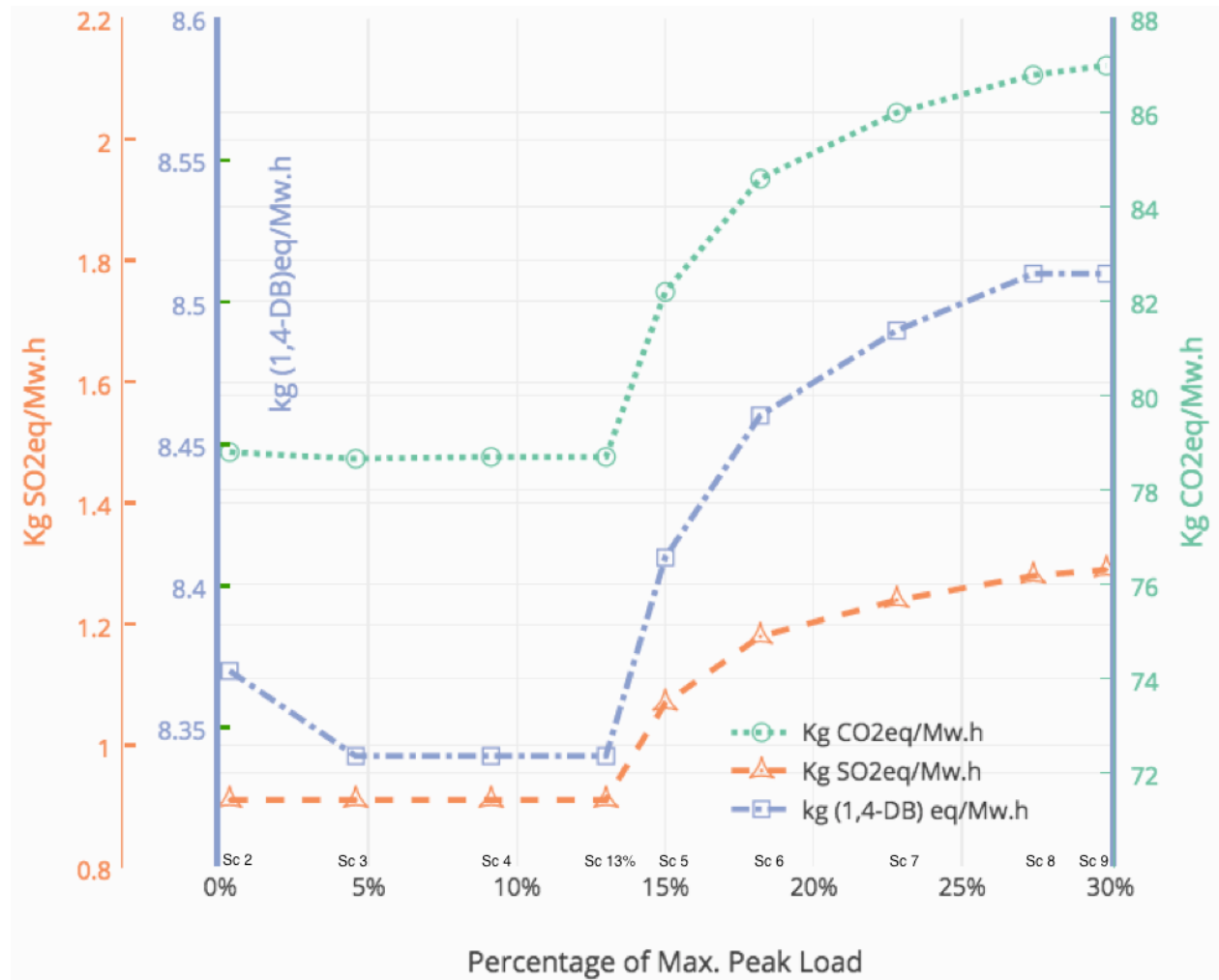
**Table 7.2: Average energy produced from PV in the scenarios.**

<b>Scenario</b>	<b>Percentage Of the maximum Peak Load</b>	<b>GWh /year</b>
2	0.32%	91
3	4.57%	1314
4	9.13%	2628
Sc 13%	13%	3880
5	15%	5642
6	18.20%	8695
7	22.80%	12958
8	27.40%	17222
9	29.86%	19508

In figure 7.2 the lower line is a theoretical projection assuming there is no need for storage. After 13% of the maximum peak load, at night, there will be shortfall in energy capacity that will result for energy storage. The amount of the extra PV for storage to cover the night time peak is significant, for example, in scenario 7 (22.8% of maximum peak load) there is approximately 5.3 GW of PV more compared to the imaginary assumption that no battery is needed (no shortfall) and all energy is consumed directly. This increment is explained in table 7.1 and table 7.2. This means after 13% of covering the maximum peak load the PV-capacities-installed/ percentage-load-covered at peak days is increased. This will affect the environmental and economic impacts that will be explained in the following sections

## 7.2 Environmental Impact for PV sector

This section quantifies the environmental impacts of the PV plants applying scenario 2 to scenario 9 showing the contribution percentages of covering the maximum peak load.



**Figure 7.4: Impact of CO<sub>2</sub>, SO<sub>2</sub> and 1,4 dichlorobenzene emissions from PV sectors per MWh due to applying scenarios 2 to scenario 9**

Figure 7.4 shows the kilograms of CO<sub>2</sub>, SO<sub>2</sub> and 1,4 dichlorobenzene emissions from PV emitted to the air for each MWh produced from the PV sectors only in the cases of scenario 2 to scenario 9.

**For Climate change:** The results in figure 7.3 show that until 13%, when no batteries are used, the CO<sub>2</sub> emissions are constant around 78.7 kg of CO<sub>2</sub> emitted for each MWh produced by PV plants.

After 13% of the maximum peak load covered by PVs, batteries are used in order to cover part of the peak load at night-time when shortfalls occur. The incremental gradient of CO<sub>2</sub> emissions starts high and become stable again after scenario 22% of peak load, heading to the constant emissions rates of the (PV+ Batteries) emissions.

Overall, the emission rate of CO<sub>2</sub> increases from 78.7 kg to 87 kg of CO<sub>2</sub> when 29.86% of the maximum peak load is covered (scenario 9) compared with no storage needed. Despite the substantial difference (13% against 29.86%) between the peak loads and the number of batteries introduced, the increase in CO<sub>2</sub> emission rates is low compared to the case when no batteries are used (under 13%); an increase of only 10.4%. The results are shown in table 7.3.

**Table 7.3: Emissions rates from PV sector in the scenarios.**

<b>Scenario</b>	<b>Percentage Of maximum Peak Load</b>	<b>kg CO<sub>2</sub>/MWh</b>	<b>kg SO<sub>2</sub>/MWh</b>	<b>kg 1,4 dichlorobenzene<sub>eq</sub>/MWh</b>
2	0.32%	78.80	0.91	8.37
3	4.57%	78.76	0.91	8.34
4	9.13%	78.70	0.91	8.35
Sc 13%	13.00%	78.62	0.91	8.33
5	15.00%	82.20	1.07	8.41
6	18.20%	84.60	1.18	8.46
7	22.80%	86.00	1.24	8.49
8	27.40%	86.80	1.28	8.51
9	29.86%	87.00	1.29	8.51

Despite the use of batteries increasing the amount of CO<sub>2</sub> emitted per MWh from the PV, it is still lower than using conventional power (785.2 kg CO<sub>2</sub>/MWh). This makes the PV power plants more favourable considering the CO<sub>2</sub> emissions because it will decrease the overall emissions in the scenarios, even if batteries are used.

**For Terrestrial Acidification:** The results in figure 7.3 show for scenarios under 13% when no batteries are used, the SO<sub>2</sub> emissions are constant around 0.91 kg of SO<sub>2</sub> emitted for each MWh produced by PV plants. After 13% of the maximum peak load covered by PVs, batteries are used. The emission rate of SO<sub>2</sub> increases; the incremental gradient of SO<sub>2</sub> emissions starts high and become stable again after scenario 22% of peak load, heading to the constant emissions rates equal to the (PV+ Batteries) emissions. The emission of scenario 9 (29.86%) is 1.29 kg of SO<sub>2</sub>/MWh with increment of 41% if compared to scenarios with no storage (before 13%) this increment is because of using batteries.

**For Human Toxicity:** Figure 7.3 present the human toxicity in 1,4 dichlorobenzene equivalent emissions. The emissions are almost constant (decreases slightly) between scenarios 2 to 13%. This decrease is because of the added PV panels to the fixed operation and maintenance ,where PV emission rates are lower than the existing (PV+operation and maintenance) emission rates. After 13% the emissions increases from 8.34 to 8.51 kg 1,4-DB/MWh in scenario 9; this increase is because of the introduction of batteries.

**In summary** the environmental emissions, CO<sub>2</sub>, SO<sub>2</sub> and 1,4-db, from PV plants are generally constant when no storage is needed. However, when storage is needed the emissions increases when using batteries. The gradients of the three emissions is relatively high right after 13% and becomes stable after 22% of maximum peak load covered heading to constant emissions rates equal to the (PV+ Batteries) emission rates. The major contributor to these emissions comes from the manufacturing phase of the batteries (as shown in section 5.3).

This emission rates discussed in this section are related to the PV plants only for the scenarios, the overall emissions rates for the scenarios after being combined with conventional plants will be shown in the next section.



### 7.3 Environmental Impacts (Conventional +PVs combined)

This section quantifies the net environmental impacts for each of the scenarios in terms of the contribution percentages of covering the maximum peak load.

To calculate the combined per MWh emissions, the total emissions from both conventional plants and PV plants need to be calculated. The different amounts of energy produced (MWh) from both sources affects the overall emissions rates. Figure 7.5 shows the total CO<sub>2</sub> emissions from PV and conventional power plants. Despite the increase of the CO<sub>2</sub> emissions from PVs for the scenarios, the total emissions is decreasing because of the high emission reduction from conventional plants that makes the emission increment from PV negligible. This means, in this case, the total CO<sub>2</sub> emissions decreases even with the highest use of batteries (that increase the emissions from PV plants).

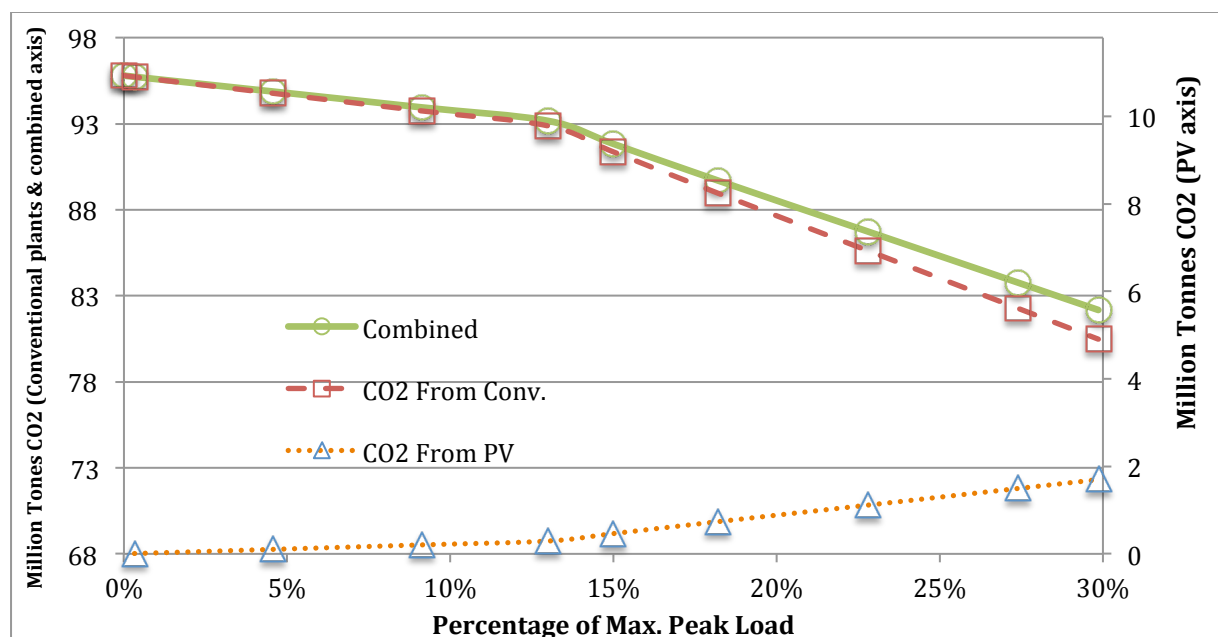


Figure 7.5: Total CO<sub>2</sub> emissions from the scenarios for year 2030.

Figure 7.6 shows the total SO<sub>2</sub> emissions from PV and conventional power plants. Despite the high rate increase of the SO<sub>2</sub> emissions from PV, the total emissions increases with lower rates because of the high emission amounts from conventional plants makes the emission increment from PV less affecting.

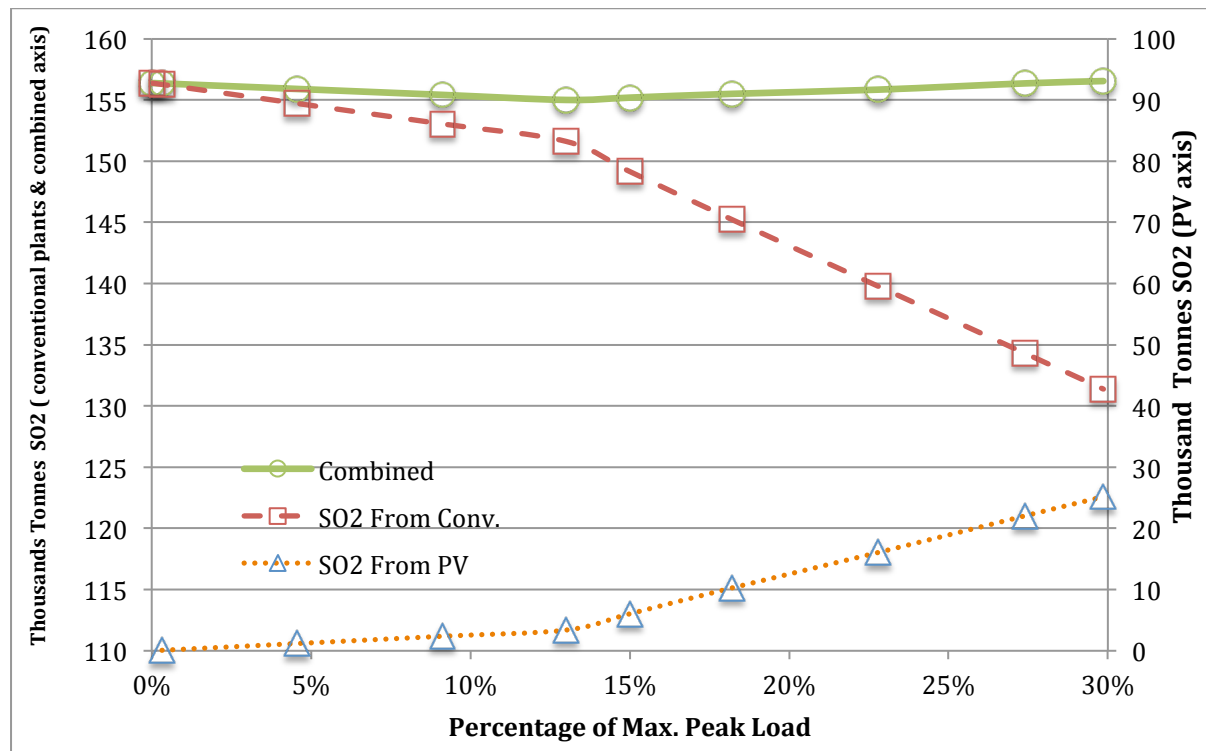
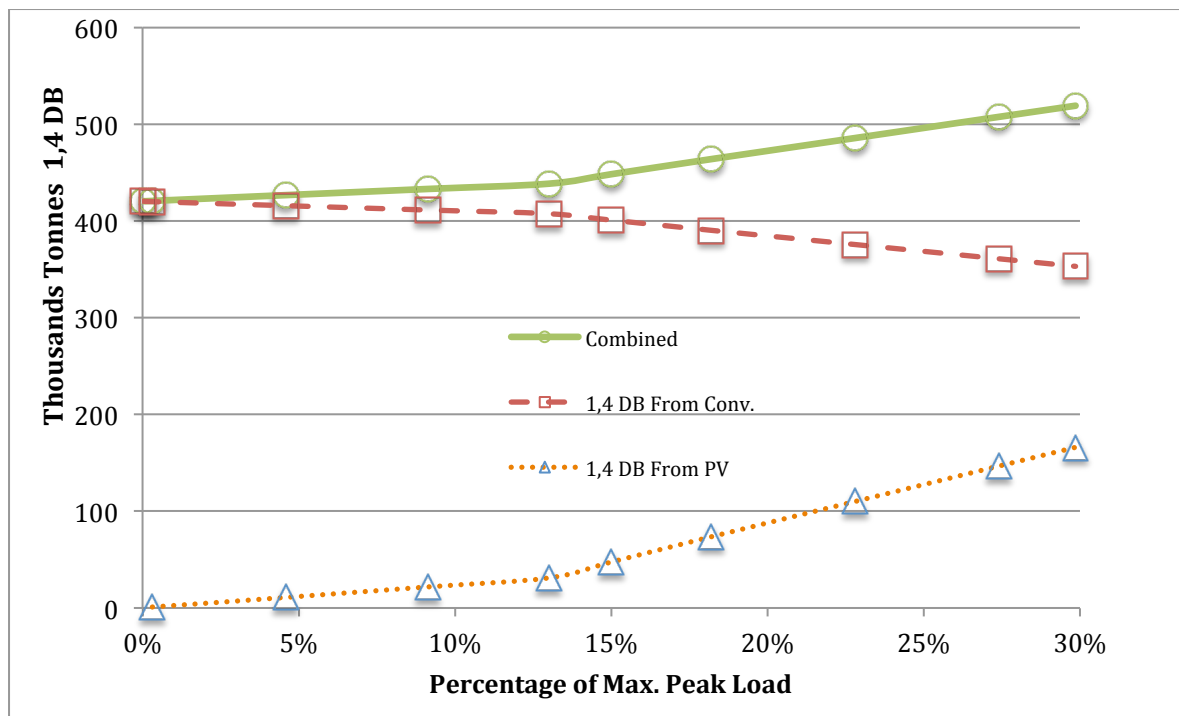


Figure 7.6: Total SO<sub>2</sub> emissions from the scenarios for year 2030.

The same concept is applied on human toxicity (kg 1,4 DB<sub>eq</sub>), figure 7.7 shows the total emissions of 1,4DB from PV and conventional sources.

The 1,4DB emission decreases from the conventional plant but with very low rates compared with the increase from the PV. The total emissions are increasing because of the high emission increment from PV plants.



**Figure 7.7: Total 1,4 DB emissions from the scenarios for year 2030.**

This means that the overall emissions rates gradients will be different after combining PV with conventional plants; the overall results for the emissions per unit of energy are shown in figure 7.8.

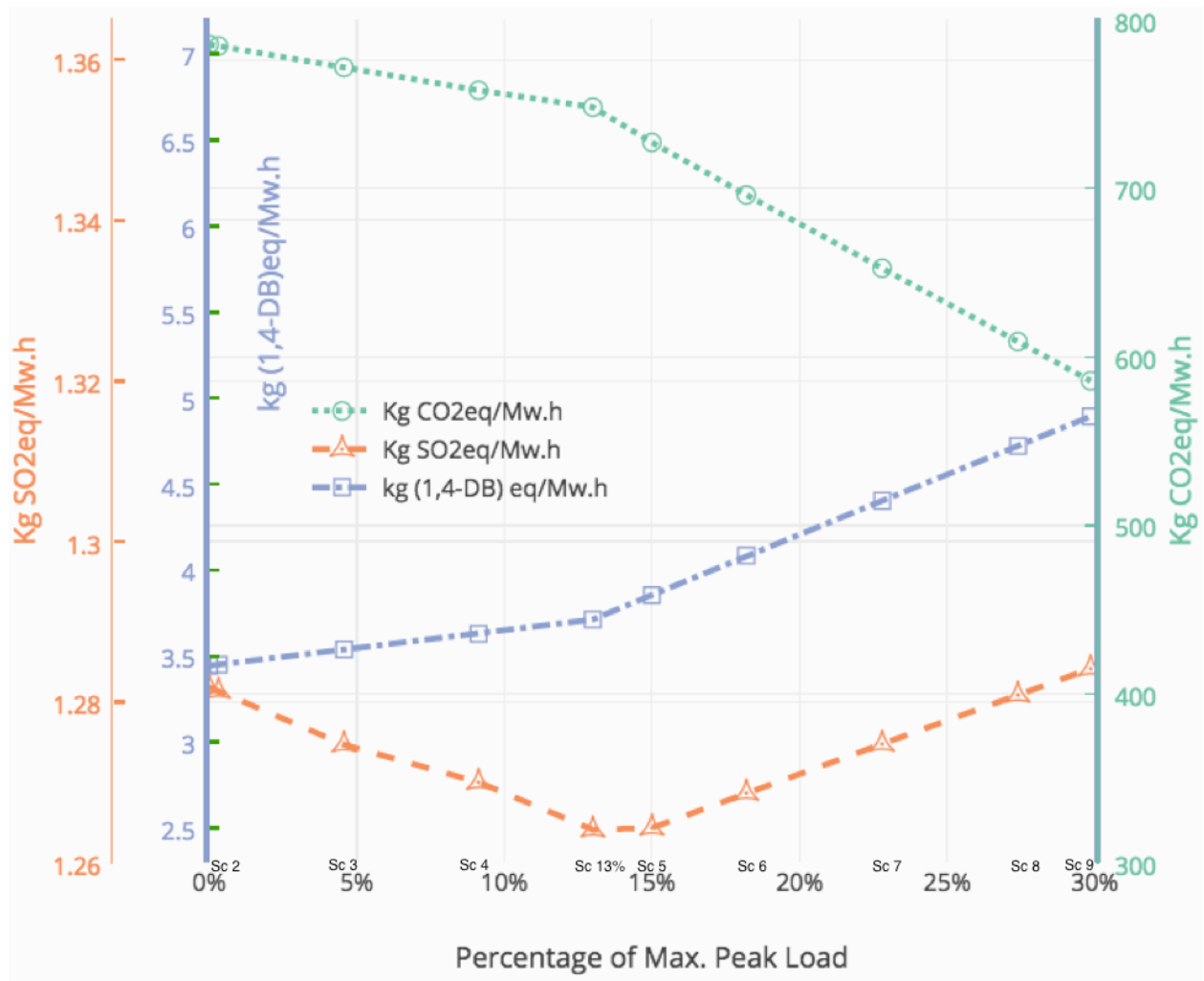


Figure 7.8: Impact of CO<sub>2</sub>, SO<sub>2</sub> and 1,4 dichlorobenzene emissions per MWh for the scenarios (PV+ conventional plants).

Figure 7.7 shows the kilograms of CO<sub>2</sub>, SO<sub>2</sub> and 1,4 dichlorobenzene (1,4DB) emitted for each MWh produce in the cases of all the scenarios.

**For Climate Change:** The results show that the more electricity peak load dependent on PV source the less kilograms of CO<sub>2</sub> emitted per MWh. Reaching to maximum reduction in scenario 9.

Starting from 785.2 kg of CO<sub>2</sub>/MWh emitted when no PV is used (scenario 1) to 585.6 kg CO<sub>2</sub>/MWh produced in scenario 9 that is covering 29.86% of the maximum peak load, this means a reduction of 25% of emissions when scenario 9 is applied.

The decrement (slope) of CO<sub>2</sub> emissions is linear with the increased dependent on PV until reaching 13% of covering the maximum peak load. This is because of the increased produced energy from PV (and decreased energy produced from conventional) with their low emission rates.

After 13% batteries are used to cover the shortfall capacity at night time, this will result with a higher amount PV-capacities-installed/ percentage-load-covered as explained in section 7.1. Hence, more energy produced from PV per percentage of peak load (compared with no batteries) with less from conventional resulting in the steeper slope shown in figure 7.7. The detailed results are shown in table 7.4.

**Table 7.4: Overall emission rates the scenarios (PV+ conventional).**

Scenario	Percentage Of maximum Peak Load	kg CO <sub>2</sub> /MWh	kg SO <sub>2</sub> /MWh	kg 1,4 dichlorobenzene <sub>eq</sub> /MWh
1	0%	785.20	1.28	3.44
2	0.32%	784.25	1.28	3.45
3	4.57%	771.60	1.27	3.53
4	9.13%	758.00	1.27	3.63
Sc 13%	13%	748.80	1.26	3.71
5	15%	727.09	1.26	3.85
6	18.20%	695.96	1.26	4.08
7	22.80%	652.47	1.27	4.40
8	27.40%	608.99	1.28	4.72
9	29.86%	585.68	1.28	4.89

**For Terrestrial Acidification:** SO<sub>2</sub> emissions are reduced depending on the increment of PV to cover the maximum peak load until 13% where at this point, 1.32% of annual SO<sub>2</sub> emissions are reduced. After that, the emissions of SO<sub>2</sub>/MWh start to increase due to the use of the batteries until reaching 1.280 kg of SO<sub>2</sub>/MWh at scenario 8 that is almost equal to scenario 1. When applying scenario 9 (29.86% of peak load) the annual emissions of SO<sub>2</sub> is increased by 0.234%. The reduction of the SO<sub>2</sub> emissions is witnessed between scenarios 2 and 7 but not in scenarios 8 and 9 where the emissions start to increase.

The SO<sub>2</sub> decrease with the increase of PV capacities until 13% of maximum peak load. This is because when no batteries are used, the SO<sub>2</sub> emission rates per MWh from PV plants are less than the conventional plants. After 13%, when batteries are introduced, the emissions from the PV+Batteries plants become higher than the conventional plants SO<sub>2</sub> emission rates, hence, with more capacity from PV, higher overall SO<sub>2</sub> emissions.

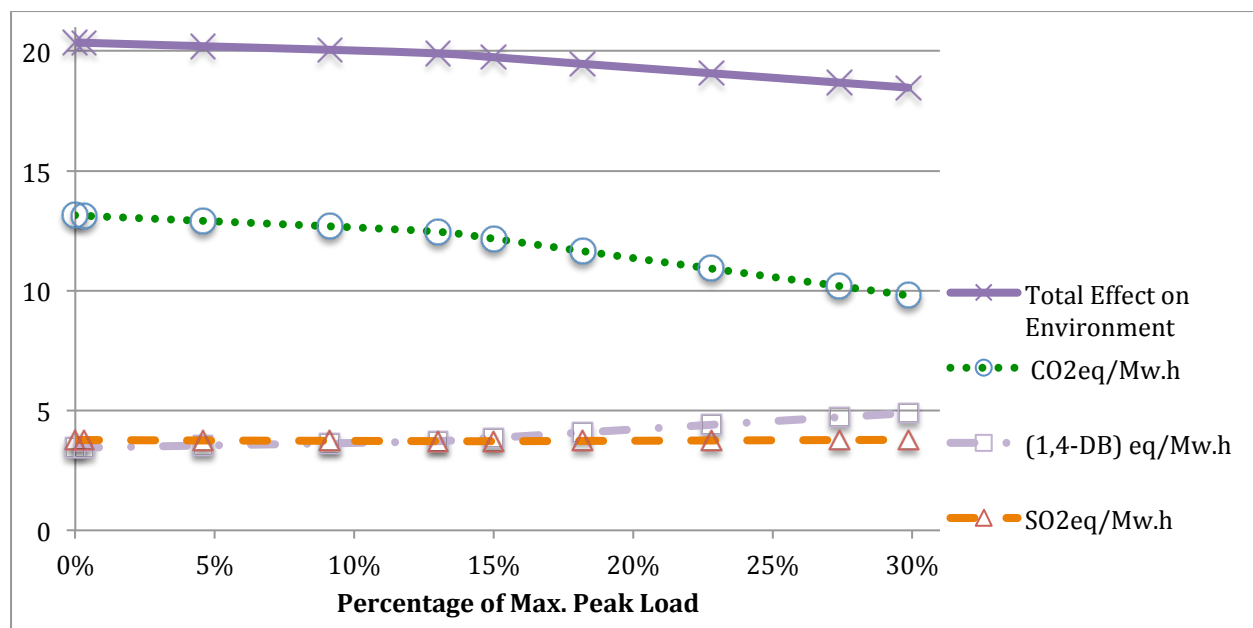
**For Human Toxicity:** the potential expressed as the reference unit kg 1,4 dichlorobenzene (1,4-DB<sub>eq</sub>). The results shows that the more the maximum peak load depends on PV, the higher the 1,4-DB<sub>eq</sub>. this is due to the emissions of substances such as heavy metals. When applying scenario 9, the annual (1,4-DB<sub>eq</sub>) emissions increase by 42% compared to scenario 1.

The 1,4-DB<sub>eq</sub> emission rates from PV are higher than the conventional plants, hence, higher overall emission rates when combining PV with conventional plants. After 13% when batteries introduced the amount of PV-capacities-installed/ percentage-load-covered is increased resulting in more energy from PV plants which explains the steeper slope.

**In summary** the climate change (CO<sub>2</sub> emissions) decrease with the increase use of the PV source. Terrestrial acidification (SO<sub>2</sub> emissions) overall decrease when using PV, the minimal emission occurs when 13% of maximum peak load from PV. Human toxicity increases when increasing the amount of PV used. Generally introducing batteries (after 13%) increase the overall environmental impact.

The three environmental impacts take different patterns when changing the scenarios, however, these impacts amounts have different influences on the environment. In order to compare between the three environmental impacts on the environment they have to be normalized.

**Normalized environmental impact based on LCA:** The LCA normalization results obtained for the three environmental impacts are used in determining the environmental impacts. To normalize the environmental impacts, impacts obtained per unit of energy are divided by average yearly environmental load in a country or continent, divided by the number of inhabitants. Worldwide reference is used since the stages of the scenarios, manufacturing, sea transportation and use phase, are distributed internationally (PRé, 2016). Based on the normalization of the LCA environmental impacts, it would appear that PV is beneficial on aggregate (Figure 7.9), even with battery storage.



**Figure 7.9: Normalized LCA environmental impacts.**

If, for example, global warming is excluded then PV would be seen to be deleterious overall, even without the use of battery storage. i.e. it depends on the choice of the impacts.

## 7.4 Economic Impact for PV sector

This section calculates the Economic impacts, the LCOE for the PV plants only, applying scenario 2 to scenario 9 showing the contribution percentages of covering the maximum peak load. Table 7.5 shows the results of the Levelized Cost of Electricity (LCOE), which is the energy costs per MWh. The results in each scenario category show the most likely, most beneficial (less cost) and less beneficial (more cost) results that could be implemented (detailed in section 6.4). The results in the scenarios until 13% are similar. After 13%, when the batteries are introduced, the cost starts to rise appreciably. For instance, after the introduction of the batteries, from the 13% scenario to 15% scenario, the cost increases from \$53.3 to \$62.77 per MWh in the most likely category. The increment is related to the storage expenses (batteries). After 22% scenario, the increment becomes stable heading to fixed cost of approximately \$75/MWh which is equal to the PV+ Batteries LCOE as shown in figure 7.10. This is because the relatively expensive storage part (batteries+ PVs) is increasing and added to the less expensive part (PV only) that is constant.

**Table 7.5: LCOE results for energy from PV plants (economic sensitivity analysis).**

<b>Scenario</b>	<b>Percentage of Max. Peak Load</b>	<b>Most Likely (\$/MWh)</b>	<b>More Beneficial (\$/MWh)</b>	<b>Less Beneficial (\$/MWh)</b>
2	0.32%	53.3	49.5	53.43
3	4.57%	53.3	49.5	53.43
4	9.13%	53.3	49.5	53.43
Sc 13%	13%	53.3	49.5	53.43
5	15%	62.77	58.3	69.94
6	18.20%	69.19	64.28	77.1
7	22.80%	73.11	67.9	81.46
8	27.40%	75.08	69.74	83.66
9	29.86%	75.79	70.39	84.45



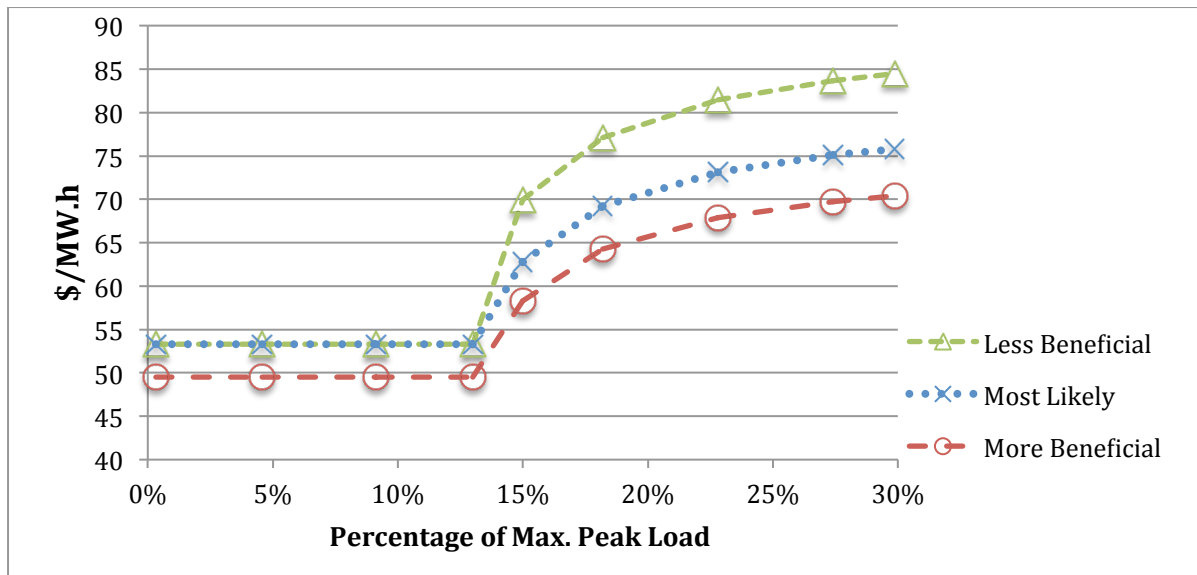


Figure 7.10: LCOE for PV plants due to applying scenarios 2 to 9 (economic sensitivity analysis).

In the Most Likely category, the cost increases from \$53.3 in scenarios equal or below 13% to \$75.79 per MWh in scenario 9. This means 42% increase in cost because the introduction of storage. However, even in the maximum cost of energy that is in Less Beneficial category in scenario 9, the LCOE \$84.45 is lower than the LCOE from the conventional plants \$121.64.

To have favourable economic PV source, the LCOE from the PV sector should be lower than the conventional plants LCOE. This is true in the calculation assuming the oil price is 50\$/Bbl. However, LCOE from conventional plants are highly dependent on oil price (figure 6.2), therefore oil prices should be considered.

If scenarios 0-13% is considered, the oil price should not be below \$10.1/Bbl. Otherwise the cost of energy from PV (\$53.3) would be higher than the conventional cost. If scenarios chosen with considerable batteries usage (18-30%), the oil price should not be below \$15.2/Bbl. otherwise the LCOE from PV sector (\$62/MWh) would be higher than the conventional cost.

Noting that since 1975 until present, OPEC oil prices did not drop to \$15.2/Bbl. The minimum price was at \$16.95 in November 1998 (inflation adjusted) (OPEC, 2016).

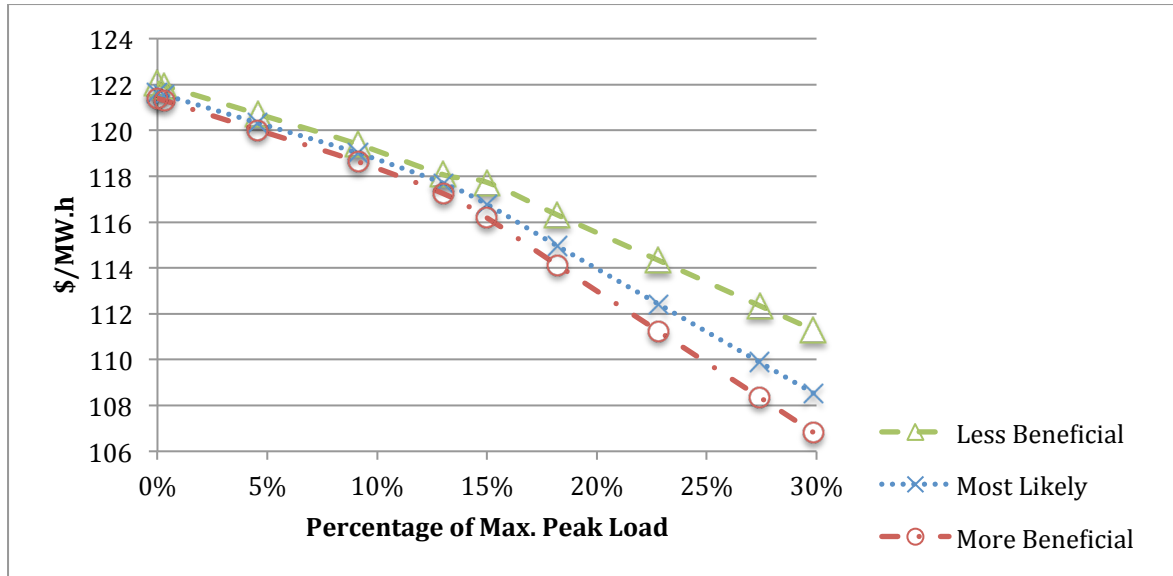
## 7.5 Economic Analysis (Conventional +PV combined)

Table 7.6 shows the LCOE results of the scenarios for year 2030. It shows the LCOE of different percentages of maximum peak load from PV. The results show that, based on \$50/Bbl oil price, the combined cost of conventional and PV sources decrease by investing more PV. LCOE ranges, in the most likely scenario, \$121.64 when using no PV to \$108.53 when depending 30% on PV to cover the maximum peak load.

**Table 7.6: LCOE results for from the scenarios (economic sensitivity analysis).**

<b>Scenario</b>	<b>Percentage of Max. Peak Load</b>	<b>Most Likely (\$/MWh)</b>	<b>More Beneficial (\$/MWh)</b>	<b>Less Beneficial (\$/MWh)</b>
1	0%	121.64	121.4	122.04
2	0.32%	121.54	121.30	121.94
3	4.57%	120.32	120.01	120.71
4	9.13%	119.00	118.63	119.39
Sc 13%	13%	117.69	117.24	118.07
5	15%	116.77	116.18	117.73
6	18.20%	114.95	114.12	116.00
7	22.80%	112.42	111.24	114.33
8	27.40%	109.89	108.36	112.35
9	29.86%	108.53	106.82	111.29

As shown in figure 7.11, after 13% of maximum peak load covered by PV, when introducing batteries, the gradient of the net cost decrease despite of the increased cost from PV plant. The reason behind this is because the maximum LCOE, when using batteries, from PV plants is lower than the LCOE from conventional plants. And the extra electricity produced from the extra PVs to charge the batteries because of the increased PV-capacities-installed/percentage-load-covered as explained in section 7.1.



**Figure 7.11: Overall LCOE for the future scenarios (economic sensitivity analysis).**

The results show that the government can have a reduction of 10.7% of the cost of MWh produced when depending 30% of peak load from PV.

The LCOE reflects the total expenses on the government of Kuwait, for example, figure 7.12 shows the total cost for electricity produced in year 2030. Overall the total cost of the electricity decreases if Kuwait increases the dependence on PVs. For example if 15% of maximum peak load is produces from PVs, the total cost for year 2030 would decrease from \$14.84 Bn to \$14.28 Bn saving approximately \$560 million. If Kuwait depends 30% of the maximum peak load from PV this will reduce the overall cost of electricity by approximately 10.7%.

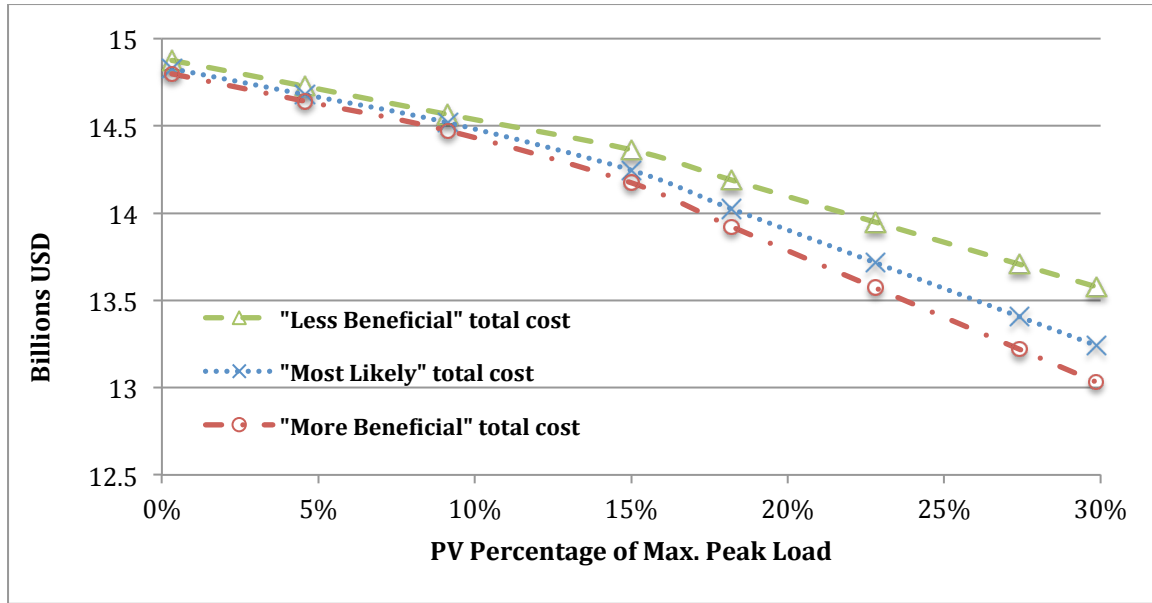


Figure 7.12: Reduction in cost of electricity through investment of PV.

In summary, the LCOE of the future scenarios decrease with the increase use of PV even after the introduction of batteries. Scenarios with batteries have higher LCOE from PV plants, however, even with scenario 9 with maximum LCOE from PV, the total LCOE for the scenarios after combination is decreasing. That is because the maximum LCOE from PV is lower than the LCOE from conventional plants, i.e. the more PV utilization leads to less overall cost.

## 7.6 Overall Results

As the results show in the previous sections, the more Kuwait depends on PV the less is the LCOE hence, decreases the overall cost of the electricity. However, after applying LCA, the environmental impacts take different patterns for applying different scenarios. Considering all the three impacts and normalizing them result an overall decrease of the impacts. However, if only cost and human toxicity is considered and assumed to have equal weights, that may not be in accordance to reality (the purpose is to demonstrate how the technique could be used), in valuing the scenarios, this will lead to a multi objective problem because the two are taking different patterns i.e. more PV will result in less cost but more human toxicity. Pareto analysis will be used as discussed in the methodology (section 4.3). The target is to optimally minimize both the costs and also the amount chosen emissions in to environment.

To show how this might work in practice, as shown in section 4.3, Figure 7.13 shows a Pareto front analysis for cost against Human Toxicity. The results data of the cost are divided by their maximum and minimum values of objective range, and the same will be applied to human toxicity. The resultant normalized points will be between 0-1 to have equal emphasis on the decision as assumed based on Pareto Front concept. Normalisation in this framework means that the costs/impacts are scaled from 0 to 1, where 1 represents the maximum cost/impact recorded in the data. Based on Pareto concept, the shorter the distance of the points to the origin the better.

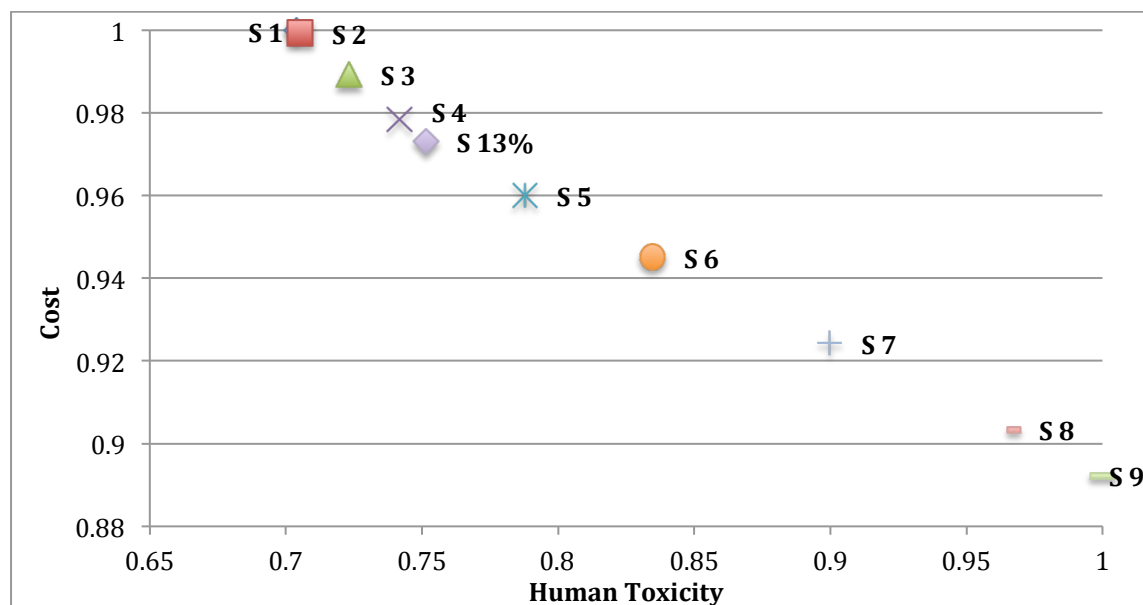


Figure 7.13: Pareto Front showing normalized cost and human toxicity.

From the graph shown in Figure 7.12, the optimal scenarios are scenarios 1-Sc 13% (Table 7.7), with between 0 and 13% of maximum Peak load from PV. The differences between the optimal scenarios are low (from 121.6\$ to 119\$ and from 3.44 1,4DB to 3.63 1,4DB respectively) In addition, the particular analysis is only using one form of environmental impact; other impacts, or combinations of impacts, might give different results. In particular, as figure 7.8 showed, once normalised global warming impacts are taken into account, the results are straightforwardly beneficial for PV and therefore scenario 9 would be preferred (with no need for a Pareto analysis).

**Table 7.7: Distances of Pareto points to the origin.**

<b>Scenario</b>	<b>Distance from Origin</b>
<u>1</u>	<u>1.22</u>
<u>2</u>	<u>1.22</u>
<u>3</u>	<u>1.22</u>
<u>4</u>	<u>1.22</u>
13%	<u>1.22</u>
5	1.24
6	1.26
7	1.28
8	1.32
9	1.34

## 7.7 Summary

This chapter showed the discussion of the results of all the scenarios created. First section showed the influence on the amount of PV and batteries capacities installed after the need of storage. For the environmental impact, the results show that the use of storage (batteries) increases the emissions from the PV sectors in the scenarios, however, after combining the two sources (PV & conventional plant), the emissions take different patterns. Since the three emissions have different influence on the environment, it is normalized. The results show, overall, the impact of the emissions is decreasing when increasing PV deployment. For the economic impact, the result show that storage increase the LCOE from the PV sectors in the scenarios, however, after combining the two sources, the LCOE decrease with the increase deployments of PV. Finally in case of impacts considered take different patterns, the multi-objective problem is solved using Pareto Front method to find the optimum scenarios.

## 8. CONCLUSION AND FUTURE WORK

### 8.1 Conclusion

The aim of this research is to create a combination of approaches to assess the economic and environmental benefits of adopting PV for electricity generation in Kuwait. The aim has been met through four objectives:

*First Objective - Identify future energy need and RE strategy for Kuwait:* It has been shown that, there is a continuous need to build new power stations to cover the high peak loads in summers in Kuwait, and the availability of the solar radiation in Kuwait area is high. Moreover, there are political, economic and environmental drivers that guided Kuwait to set their RE adoption strategies.

Fossil fuels, mainly oil, are the main source of energy worldwide. With the increasing energy demand, other renewable sources have to be utilized to avoid future energy depletion. Moreover, fossil fuels are related to many negative impacts, such as environmental impacts including climate change. The international community, through global protocols and agreements, already took commitments in order to solve this global issue.

Since GCC countries are economically highly dependent on oil, and at the same time highly depending on fossil fuels for energy generation with high subsidies from their governments. Finding new RE source will have positive economic impacts on these countries (lowering the cost of electricity will lower the subsidies from the government) and use oil, from fuel to increase exportation. Moreover, geographically, the literature show high irradiance with positive potential of applying solar energy in the GCC countries with minimal actual application of RE. Literature shows PV is most suitable for this area because of its technical specifications and employments rates. Based on that, the potential of the Photovoltaic as a renewable energy power plant has been investigated and valued environmentally and economically.

*Second objective - Create scenarios for potential future energy mixes:* These factors led to study the environmental and economic impacts of applying PV for future electricity mixes in Kuwait as exemplar for GCC countries since they share similar inner energy policies. The data for Kuwait are used as an input for the future scenarios of applying PV run by the government with its specific geographic, economic and electrical data. Nine future potential scenarios are created showing different levels of PV deployment. For other GCC countries,



different inputs should be used to determine the estimated impacts of future scenarios (energy mixes).

*Third objective - Select techniques to measure environmental and economic impacts:* The environmental impacts have been estimated using LCA approach including the life of each scenario (from cradle to grave) to quantify the environmental impacts. LCOE approach is used to determine the economic impacts for the scenarios. Estimation of the future economic and selected environmental impacts of applying the scenarios created has been performed. It has been clarified that selecting these impacts is important in determining the value of the scenario.

For the environmental side, the results show that scenarios that PV covers 13% of the maximum peak load or less, the PV plants have similar environmental impacts but lower than the conventional power plants impacts (except human toxicity which is slightly higher than conventional). Scenarios covering more than 13% of maximum peak load require utilizing batteries for storage to be used at night. Because of the batteries, the environmental emissions increase with the increase of percentage of covering the peak load (increase the need for batteries).

However, after combining the two sources (PV + Conventional) to find the overall impacts for the scenarios, the results show that the more depending on PV in electricity mix, the lower emissions of climate change and Terrestrial Acidification however increases the human toxicity.

For the economic side, the results show that for scenarios that PV covers 13% of the maximum peak load or less, the PV plants have similar cost of the electricity (LCOE) and lower than the conventional power plants electricity cost. Scenarios covering more than 13% of maximum peak load require utilizing batteries for storage. Because of the batteries, the cost increases with the increase of percentage of covering the peak load (increase the need for batteries) but still lower than conventional power plants electricity cost. However, after combining the two cost sources (PV + Conventional) to find the overall LCOE for the scenarios, the results show that with more PV in the electricity mix, the cost of electricity is reduced.

The calculation assumed the oil price is 50\$/Bbl. However, LCOE from conventional plants are highly dependent on oil price. If scenarios 0-13% are considered, the oil price should not be below \$10.1/Bbl. Otherwise LCOE from PV (\$53.3/MWh) would be higher than the

conventional cost. If scenarios chosen with considerable batteries usage (18-30%), the oil price should not be below \$15.2/Bbl. otherwise the cost of energy from PV sector (\$62/MWh) would be higher than the conventional cost. However, based on historical oil prices data, oil prices are unlikely to affect the cost benefits of the PV plants.

Overall, the environmental and economic impacts decrease with the increase of implementing of PV plants in Kuwait, at least until the maximum (30%) considered in this research.

*Fourth objective - Create process and evaluate benefits of future energy mixes: Beside LCA and LCOE, LCA normalization is done to find the overall environmental impacts of the three emissions. The results show that the deployment of PV lowers the overall environmental impact. However, it depends on the choice of the environmental emissions. If a different combination of impacts is considered, impacts may take deferent patterns leading to multi objectives problem. Pareto front analysis has been conducted to reach the main objective (lowering the impacts).*

The combination of approaches applied in this study is used to identify the optimal future mix in Kuwait. However if the inputs modified, it can be applied to all GCC countries with different sizes/mixes and RE technologies. This will enable policy makers in GCC countries to compare various energy mixes and hence determine whether their current and future energy strategies are appropriate.

The contribution to knowledge from this research is that the deployment of large scale PV technology is beneficial in Kuwait economically and environmentally at least until 30% of the maximum peak load of electricity. The results have implications for other GCC countries with similar geographical, political and energy drivers; the methodology used in this research would be appropriate for these contexts.

## 8.2 Future Work

This research has shown the optimal scenarios with the lowest negative impacts of the proposed future energy mixes using PV plants, built based on the geographic and energy status of Kuwait as an oil-based economy country. This suggests a high potential of positive impacts, economically and environmentally, for GCC countries. Leading to the need for further studies of large scale other RE technologies in these countries as oil based economy, using the same proposed approaches models to be more comparable, and assessing the other types of RE technology in the region.

As the LCA approach applied estimated the future environmental impacts on certain emissions chosen based on Kuwaiti situation, other impacts can be included in the environmental studies to suit other countries such as land use that may affect the overall impact.

It is assumed that the oil saved from used as fuel in conventional power plants is exported which is the case of GCC countries. However this may not be true for other oil-based economy countries. Therefore the nature of supply and demand should be studied and considered. The study assumes that the PV plants are in continuous connection to the grid during production times without interruption. Experimental studies are recommended to be done to have a deeper understanding of actual operating behavior of new plants. Including large-scale energy production data for PV and hence actual LCOE. Also including risk analysis of climate potential interruption such as storms.

The applicability of the scenarios in this research may face limitations. Due to the nature of the unstable global pressures, governments may revise their motivation of deploying RE in the future. Moreover, inner policies (from the government or Kuwait National Assembly) may affect the applicability of scenarios, for example, balancing variable power source, also may affect type of RE technology used.

### 8.3 Publications

The following publications have been made as a result of this research:

- *Article submitted* to Energy Policy: Fahad Kh. Alazemi, Linda Newnes, and Steve Cayzer. 2017. Environmental and Economic Analysis of Photovoltaic Energy in Kuwait.
- F. Alazemi, L. Newnes. 2014. Financial and Environmental Trade-off Analysis for Kuwait as Oil Based Economy to Utilize Green Energy. The 12th International Conference on Manufacturing Research (ICMR2014), pp. 253-258.

## 9. REFERENCES

National Research Council, 2010. *Advancing the Science of Climate Change*, Washington DC, USA: The National Academies Press.

Abdmouleh, Z., Alammari, R. A. M. & Gastli, A., 2015. Recommendations on renewable energy policies for the GCC countries. *Renewable and Sustainable Energy Reviews*, Volume 50, pp. 1181-1191.

Ahmed, Z., Kazem, H. A. & Sopian, K., 2014. *Effect of dust on Photovoltaic performance: Review and Research status*. [Online]

Available at:

[http://www.academia.edu/4117648/Effect\\_of\\_Dust\\_on\\_Photovoltaic\\_Performance\\_Review\\_and\\_Research\\_Status](http://www.academia.edu/4117648/Effect_of_Dust_on_Photovoltaic_Performance_Review_and_Research_Status)

[Accessed 5 July 2014].

Al-Badi, A. H., Albadi, M. H., Al-Lawati, A. M. & Malik, A. S., 2010. *Economic perspective of PV electricity in Oman*, Muscat, Oman: Elsevier - Energy.

Alberici, Sacha, Boeve, Sil, Breevoort, Pieter van, Deng, Yvonne, Förster, Sonja; Ann, G, Gastel, Valentijn van, Grave, Katharina, Groenenberg, Heleen, Jager, David de, Klaassen, Erik, Pouwels, Willemijn, Smith, Matthew, Visser, Erika de, Winkel, Thomas, Wouter, K., 2014. Subsidies and costs of EU energy: Final report. [Online]

Available at:

[https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy\\_11\\_Nov.pdf](https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf)

Al-Enezi, F. Q., Sykulski, J. K. & Ahmed, N. A., 2011. *Visibility and Potential of Solar Energy on Horizontal Surface at Kuwait Area*, Chengdu, China: Elsevier - SciVerse ScienceDirect.

Al-Hasan, A. Y., 1997. *Electricity Generation Cost Between Proposed Photovoltaic Station and Conventional Units in Kuwait*, Kuwait, Kuwait: Elsevier - Renewable Energy.

Allen, L., Cohen, M. J., Abelson, D. & Miller, B., 2014. *Fossil Fuels and Water Quality*. [Online]

Available at:

[http://worldwater.org/wp-content/uploads/sites/22/2013/07/chapter\\_4\\_fossil\\_fuel\\_and\\_water\\_quality.pdf](http://worldwater.org/wp-content/uploads/sites/22/2013/07/chapter_4_fossil_fuel_and_water_quality.pdf)

Alnaser, W. E. & Alnasere, N. W., 2011. *The status of renewable energy in the GCC countries*, Manama, Bahrain: s.n.

Alnatheer, O., 2005. *Environmental benefits of energy efficiency and renewable energy in Saudi Arabia's electric sector*, Riyadh: Elsevier - Energy Policy.

Al-Olaimy, T., 2013. *Climate change impacts in MENA: The Gulf*. [Online]  
Available at:

<http://adoptanegotiator.org/2013/11/19/climate-change-impacts-in-mena-gulf/>  
[Accessed 10 June 2014].

Alotaibi, S., 2010. *Energy consumption in Kuwait: Prospects and future approaches*, Kuwait, Kuwait: Elsevier - Energy Policy.

Al-Rashed, A., Beyrouthy, T. & El-Rifaie, A. M., 2016. Feasibility Study of Solar Energy Integration for Electricity Production in Kuwait. *International Journal of Engineering and Technical Research (IJETR)*, 5(1), pp. 84-87.

Altostratus Inc, 2011. *Air-Quality impacts of heat Island control and Atmospheric effects of urban Solar Photovoltaic arrays*. [Online]  
Available at:

<http://www.energy.ca.gov/2013publications/CEC-500-2013-061/CEC-500-2013-061.pdf>  
[Accessed 10 June 2014].

Ameer, B. & Krarti, M., 2016. *Impact of subsidization on high energy performance designs for Kuwaiti residential buildings*. *Energy and Buildings*, Volume 116, pp. 249-6.

Anayochukwu, A. V., 2013. *Environmental Impact Assessment of Power Generation Systems at GSM Base Station Site*. [Online]  
Available at:

<http://ejee.cl/index.php/ejee/article/view/606/505>  
[Accessed 15 June 2014].

API, 2014. *Facts about Fossil fuels*. [Online]  
Available at:

<http://www.api.org/oil-and-natural-gas-overview/classroom-tools/teaching-tools/facts-fossil-fuels>  
[Accessed 6 June 2014].

Arab Sustainability Association, 2013. *Renewable energy investment in the MENA region rises 40%*. [Online]  
Available at:

[http://www.ifpinfo.com/asa/asa-news.php?news\\_id=3057](http://www.ifpinfo.com/asa/asa-news.php?news_id=3057)

Armstrong, A., Ostle, N. J. & Whitaker, J., 2016. *Solar park microclimate and vegetation management effects on grassland carbon cycling*. *Environmental Research Letter*, 11(7), pp. 1-12.

Auer, A., 2015. *Photovoltaic module decommissioning and recycling in Europe and Japan: Current methodologies, norms and future trends*. [Online]  
Available at:

[http://stud.epsilon.slu.se/7608/1/auer\\_a\\_150211.pdf](http://stud.epsilon.slu.se/7608/1/auer_a_150211.pdf)

Bachellerie, I. J., 2012. Renewable energy in the GCC countries: resources, potential, and prospects..

Badcock, J. & Lenzen, M., 2010. Subsidies for electricity-generation technologies: A review. *Energy Policy*, 38(2), pp. 5038-47.

Bae, C. & Kim, J., 2017. Alternative fuels for internal combustion engines. *Proceedings of the Combustion Institute*, 36(3), pp. 3389-3413.

Barlow, Z., 2013. *Breakthrough in hydrogen fuel production could revolutionize alternative energy market*. [Online]  
Available at:

<http://www.vtnews.vt.edu/articles/2013/04/040413-cals-hydrogen.html>  
[Accessed 27 May 2014].

Beck, F. & Martinot, E., 2004. *Renewable energy policies and barriers*. [Online]  
Available at:

[http://www.martinot.info/Beck\\_Martinot\\_AP.pdf](http://www.martinot.info/Beck_Martinot_AP.pdf)  
[Accessed May 2014].

Bedir, N., 2016. *Fostering renewable energy deployment in Kuwait-Special Report*. [Online]  
Available at:

<http://news.kuwaittimes.net/website/fostering-renewable-energy-deployment-kuwait/>  
[Accessed Feb 2017].

Best Practices Brochure 004, 2002. *Residue utilization DIDCOT coal-fired power station*. [Online]  
Available at:

<http://www.energymanagertraining.com/Journal/Best%20Practice%20Brochure-004-Feb-02.pdf>  
[Accessed 6 June 2014].

Bhutto, A. W., Bazmi, A. A., Zahedi, G. & Klemes, J. J., 2014. *A review of progress in renewable energy implementation in the Gulf Cooperation Council countries*, s.l.: Journal of Cleaner Production.

Bou-Rabee, M. & Sulaiman, S., 2015. On Seasonal Variation of Solar Irradiation in Kuwait. *International Journal of Renewable Energy Research*, 5(2), pp. 367-72.

Bou-Rabee, M., Sulaiman, S. A., Saleh, M. S. & Marafi, S., 2017. Using artificial neural networks to estimate solar radiation in Kuwait. *Renewable and Sustainable Energy Reviews*, Volume 72, pp. 434-438.

BP, 2016. BP Statistical Review of World Energy 2016, London, UK: BP.

Brady, W. J., 2011. Hydraulic Fracturing in the United States: The Laissez-Faire Approach of Federal Government and Varying State Regulations. Denver, Colorado: Grimshaw & Haring. P. C..

Branker, K., Pathak, M. J. & Pearce, J. M., 2011. A review of solar photovoltaic levelized cost of electricity, Houghton, MI: Elsevier - Renewable and Sustainable Energy Reviews.

Bringezu, Stefan, Schütz, Helmut, Pengue, Walter, O'Brien, Meghan, Garcia, Fernando, Sims, Ralph, Howarth, Robert W., Kauppi, Lea, Swilling, Mark, Herrick, Jeffrey, 2014. Assessing Global Land Use: Balancing consumption with sustainable supply. [Online]  
Available at:

[http://www.unep.org/resourcepanel/Portals/24102/PDFs/Full\\_Report-Assessing\\_Global\\_Land\\_UseEnglish\\_%28PDF%29.pdf](http://www.unep.org/resourcepanel/Portals/24102/PDFs/Full_Report-Assessing_Global_Land_UseEnglish_%28PDF%29.pdf)  
[Accessed 5 July 2014].

Buckley, T. & Nicholas, S., 2016. 2016 Year in Review: Three trends highlighting the accelerating global energy market transformation. [Online]  
Available at:

<http://ieefa.org/wp-content/uploads/2016/11/2016-Year-in-Review.pdf>

Byrne, Joseph, Mills, Luke, Strahan, David, Boyle, Rohan, Collins, Bryony, Stopforth, Kieron, Becker, Lisa, 2016. *Global Trends in RE Investment 2016*. [Online]  
Available at:

[http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres\\_0.pdf](http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf)

Capital Standards, 2013. *Kuwait Utilities Sector*. [Online]

Available at:

[http://www.infomercatiesteri.it/public/images/paes/107/files/Kuwait%20Utilities%20Sector%20Report\\_pdf%206\\_13.pdf](http://www.infomercatiesteri.it/public/images/paes/107/files/Kuwait%20Utilities%20Sector%20Report_pdf%206_13.pdf)  
[Accessed 1 July 2014].

Capitanescu, F, Rege, S, Marvuglia, A, Benetto, E, Ahmadi, A, Navarrete Gutie, T & Tiruta Barna, L. 2015. Cost versus life cycle assessment-based environmental impact optimization of drinking water production plants. *Journal of Environmental Management*.

Caravelli, J., 2011. *Beyond sand and oil, the nuclear Middle East..* [Online]  
Available at:

<http://site.ebrary.com/id/10460618>.



Cengiz, M. S. & Mamiş, M. S., 2015. Price-Efficiency Relationship for Photovoltaic systems on a Global Basis. *International Journal of Photoenergy*, pp. 1-12.

Clean Energy Results, 2012. *Questions & Answers: Ground-Mounted Solar Photovoltaic Systems*. [Online]

Available at: <http://www.mass.gov/eea/docs/doer/renewables/solar/solar-pv-guide.pdf>  
[Accessed 5 July 2014].

Climatemp.com, 2017. *Kuwait City Climate Table*. [Online]

Available at: <http://www.kuwait.climatemps.com/sunlight.php>

Council on Foreign Relations, 2013. *The Global Climate change Regime*. [Online]

Available at: <http://www.cfr.org/climate-change/global-climate-change-regime/p21831>  
[Accessed 7 June 2014].

Craig, J. R. & Vaughan, D. J., 1996. *Resources of the Earth: Origin, Use and Environmental Impact*. 2 ed. Herefordshire, UK: Prentice Hall.

Dawoud, M. A. & Al-Mulla, M. M., 2012. Environmental Impacts of Seawater Desalination: Arabian Gulf Case Study. *International Journal of Environmental and Sustainability*, 3(1), pp. 22-37.

Dia, F., Mbengue, N., Sarr, O. N., Diagne, M., Niasse, O. A., Dieye, A., Niang, M., Ba, B., Sene, C., 2016. Model Associated with the study of the degradation Based on the Accelerated Test: A Literature Review. *Open Journal of Applied Sciences*, 6( ), pp. 49-63.

Dicks, K. S., 2011. *Kuwait: Euro Solar Energy Market: challenges worth solving?*. [Online]

Available at: <http://news.pv-insider.com/concentrated-pv/kuwait-%E2%82%AC%E2%84%A2s-solar-energy-market-challenges-worth-solving>  
[Accessed 5 July 2014].

Doshi, T. K., D'Souza, N. S., Nguyen, L., Guan, T. H., Zahur, N. B., 2013. The economics of Solar PV in Singapore. *GSTF International Journal of Engineering Technology (JET)*, 2(1), pp. 53-63.

Doukas, H., Patlitzianas, K. D., Kagiannas, A. G. & Psarras, J., 2006. Renewable energy sources and rationale use of energy development in the countries of GCC: Myth or reality?, Athens: El Sevier: Renewable Energy.

Dutta, S., 2013. Oil & Gas IQ Countdown 2014: The world's biggest oil & gas companies & the industry giants who lead them. [Online]

Available at: <http://no.sotskurs.no/wp-content/uploads/2013/12/The-Worlds-Biggest-Oil-Gas-Companies-2014.pdf>

EESI, 2014. *Fossil Fuels*. [Online]

Available at: <http://www.eesi.org/topics/fossil-fuels/description#.U5K0ltk8vDc>  
[Accessed 3 June 2014].

El Fadel, M., Rachid, G., El-Samra, R., Bou Boutros, G., Hashisho, J., 2012. *Emissions reduction and economic implications of renewable energy market penetration of power generation for residential consumption in the MENA region*, Beirut, Lebanon: Energy Policy.

Elhussain, O. A. & Abdel-Magid, T. I. M., 2016. *Difference between the maximum empirical and field measured peak Watt values of thermal power system under highly sufficient solar conditions*. Khartoum, Sudan, IOP Publishing.

Embach, C., 2016. *Oil Spills: Impacts on the Ocean*. [Online]  
Available at: <http://www.waterencyclopedia.com/Oc-Po/Oil-Spills-Impact-on-the-Ocean.html>

Eni scuola, 2012. *Natural gas*. [Online]  
Available at: <http://www.eniscuola.net/en/energy/contenuti/natural-gas/>  
[Accessed 4 June 2014].

ENI, 2011. *World Oil and Gas Review*, s.l.: s.n.

Environment Canada, 2012. *Performance of Solar Photovoltaic Technologies*. [Online]  
Available at: [http://www.ec.gc.ca/scitech/B53B14DE-034C-457B-8B2B-39AFCFED04E6/ForContractor\\_721\\_Solar\\_Photovoltaic\\_Technology\\_e\\_09%20FINAL-update%202-s.pdf](http://www.ec.gc.ca/scitech/B53B14DE-034C-457B-8B2B-39AFCFED04E6/ForContractor_721_Solar_Photovoltaic_Technology_e_09%20FINAL-update%202-s.pdf)  
[Accessed June 2014].

Environment Public Authority Kuwait, 2012. *Kuwait's Initial National Communications under the United Nations Framework Convention on Climate Change*. [Online]  
Available at: <https://unfccc.int/resource/docs/natc/kwtnc1.pdf>

EPA, 2014. *Oil*. [Online]  
Available at: <http://www.epa.gov/cleanenergy/energy-and-you/affect/oil.html>  
[Accessed July 2014].

ETSAP & IRENA, 2012. *Water desalination using renewable energy: Technology Brief*. [Online]  
Available at: <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20I12%20Water-Desalination.pdf>  
[Accessed 5 July 2013].

EU\_GCC, 2013. *Renewable Energy Readiness Assessment Report: The GCC countries*. [Online]  
Available at: [http://www.eugcc-cleanergy.net/LinkClick.aspx?fileticket=Rm-kG8I\\_55o%3D&tabid=40](http://www.eugcc-cleanergy.net/LinkClick.aspx?fileticket=Rm-kG8I_55o%3D&tabid=40)

European Photovoltaic Technology, 2011. *A Strategic Research Agenda for Photovoltaic Solar Energy Technology*. [Online]  
Available at: [ftp://ftp.cordis.europa.eu/pub/technology-platforms/docs/pvtp-sra-2011-2\\_en.pdf](ftp://ftp.cordis.europa.eu/pub/technology-platforms/docs/pvtp-sra-2011-2_en.pdf)  
[Accessed 8 June 2014].

European Solar Test Installation (ESTI), 2013. *Photovoltaic Geographical Information System (PVGIS) - Interactive Maps*. [Online]

Available at: <http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en>  
[Accessed 2013].

European Commission, 2014. EU Energy Markets in 2014. [Online] Available at:  
[http://ec.europa.eu/energy/sites/ener/files/documents/2014\\_energy\\_market\\_en.pdf](http://ec.europa.eu/energy/sites/ener/files/documents/2014_energy_market_en.pdf)

Eurostat, 2016. *Greenhouse gas emission statistics*. [Online]

Available at: [http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse\\_gas\\_emission\\_statistics](http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics)

Fanidou, D., 2013. *Renewable green energy power: Technological overview of Photovoltaics, PV*. [Online]

Available at: <http://www.renewablegreenenergypower.com/technological-overview-of-photovoltaics-pv/>

[Accessed May 2014].

Fattouh, B. & Mahadeva, L., 2014. *Price Reform in Kuwait's Electricity and Water Sector: Assessing the Net Benefits in the Presence of Congestion*. [Online]

Available at: <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/04/MEP-9.pdf>

Feldman, D., Barbose, G., Margolis, R., James, T., Weaver, S., Darghouth, N., Fu, R., Davidson, C., Booth, S., Wiser, R. 2015. Photovoltaic System Pricing Trends Historical, Recent, and Near-Term Projections *2015 Edition* [Online]

Available at: <https://www.nrel.gov/docs/fy15osti/64898.pdf>

Ferroukhi, R., Ghazal-Aswad, N., Androulaki, S., Hawila, D., Mezher, T., 2013. *EU-GCC Renewable Energy Policy Cooperation: Exploring Opportunities*. [Online]

Available at: <http://eu-gcc.kcorp.net/common/publicationfile/49.pdf>

[Accessed Aug 2014].

Ferroukhi, R., Ghazal-Aswad, N., Androulaki, S., Hawila, D., Mezher, T., 2013. Renewable energy in the GCC: Status and challenges. *International Journal of Energy Sector Management*, Issue 7, pp. 84-112.

Ferroukhi, R, Khalid, A., Hawila, Diala, Nagpal, D, El-Katiri, L, Fthenakis, V, Aref, Al-Fara, 2016. *Renewable Energy Market Analysis*. [Online]

Available at:

[http://www.irena.org/DocumentDownloads/Publications/IRENA\\_Market\\_GCC\\_2016.pdf](http://www.irena.org/DocumentDownloads/Publications/IRENA_Market_GCC_2016.pdf)

Fierro, J. L. G., 2013. *Hydrogen: Production methods*. [Online]

Available at: [http://www.fgcsic.es/lychnos/en\\_EN/articles/hydrogen\\_production\\_methods](http://www.fgcsic.es/lychnos/en_EN/articles/hydrogen_production_methods)

[Accessed 5 June 2014].

First solar, 2014. *Reporting: Carbon displacement*. [Online]

Available at: <http://www.firstsolar.com/en/about-us/corporate-responsibility/carbon-reporting>

[Accessed June 2014].

Forsberg, C. W., 2008. Sustainability by combining nuclear, fossil, and renewable energy sources. *Elsevier*, 4(2), pp. 1-9.

Fronzel, M., Ritter, N., Schmidt, C. M. & Vance, C., 2009. *Economic impacts from the promotion of renewable energy technologies: The German experience*. [Online]  
Available at: [http://repec.rwi-essen.de/files/REP\\_09\\_156.pdf](http://repec.rwi-essen.de/files/REP_09_156.pdf)  
[Accessed 27 May 2014].

Frost & Sullivan, 2013. *Frost & Sullivan Whitepaper on The Future for "Green" in the GCC's Energy Sector*. [Online]  
Available at: <file:///C:/Users/SHEPHA~1/AppData/Local/Temp/Frost-and-Sullivan-Whitepaper-WFES.PDF>  
[Accessed August 2014].

Fu, Yinyin, Lui, Xin, Yuan, Zengwei, 2014. *Life-cycle assessment of multi-crystalline photovoltaic (PV) systems in China*. *Journal of Cleaner Production*.

Funk, K., Milford, J. & Simpkins, T., 2013. *Analyzing the Economic and Environmental Viability of Waste-to-Energy (WTE) Technology for Site-Specific Optimization of Renewable Energy Options*. [Online]  
Available at: <http://www.nrel.gov/docs/fy13osti/52829.pdf>  
[Accessed 27 May 2014].

Gelil, I. A., 2015. Energy Demand Profile in Arab Countries. In: L. El-Katiri & B. Fattouh, eds. *A Brief Political Economy of Energy Subsidies in the Middle East and North Africa*. s.l.:Oxford Institute for Energy Studies, pp. 84-107.

German Aerospace Center, 2005. *Concentrating Solar Power for the Mediterranean Region*. [Online]  
Available at:  
[http://www.dlr.de/Portaldata/1/Resources/portal\\_news/newsarchiv2008\\_1/algerien\\_med\\_csp.pdf](http://www.dlr.de/Portaldata/1/Resources/portal_news/newsarchiv2008_1/algerien_med_csp.pdf)  
[Accessed 10 June 2014].

Ghoneim, A. A., 2012. Environmental impacts of grid connected photovoltaic system adapted for peak load reduction in Kuwait. *Chemical Engineering Transactions*, Volume 29, pp. 1213-18.

Ghoneim, A. A., Al-Hasan, A. Y. & Abdullah, A. H., 2000. *Economic analysis of photovoltaic-powered solar domestic hot water systems in Kuwait*, Kuwait, Kuwait: Elsevier - Renewable Energy.

Gilanipour, J. & Gholizadeh, B., 2010. *The economic analysis of implementing photovoltaic solar system in the SARI station Northern of Iran*. [Online]  
Available at: [http://isro.eu.com/Nov\\_Proc/pdf%2010.pdf](http://isro.eu.com/Nov_Proc/pdf%2010.pdf)  
[Accessed 23 June 2014].

Green, R. & Staffell, L., 2016. Electricity in Europe: exiting fossil fuels?. *Oxford Review of Economic Policy*, 32(2), pp. 282-303.

Grigg, J., 2002. The health effects of fossil fuel derived particles. *Arch Dis Child*, 86(<http://adc.bmj.com/content/86/2/79.full.pdf>), pp. 79-83.

Gulf Center for Strategic Studies, 2013. *[Renewable Energy Alternatives in GCC] (in Arabic)*. [Online]

Available at: <http://www.akhbar-alkhaleej.com/12920/article/40917.html>

Hadi, M. A., Abdel-Razek, R. H. & Chakroun, W. M., 2013. *Economic Assessment of the Use of Solar Energy in Kuwait*, Kuwait, Kuwait: Global Journal of Business Research.

Hanga, Y, Qua, M & Zhaob, F, 2010. Economical and environmental assessment of an optimized solar cooling system for a medium-sized benchmark office building in Los Angeles, California. *Renewable Energy*.

Harder, E. & Gibson, J. M., 2010. *The costs and benefits of large-scale solar photovoltaic power production in Abu Dhabi, United Arab Emirates*, Chapel Hill, NC: Elsevier - *Renewable Energy*.

Hasan, A. & Sayigh, A. A., 1996. *Cost and Sensitivity Analysis for Photovoltaic Station in Kuwait*, Kuwait, Kuwait: College of Technological Studies - Kuwait.

Hashem, H., 2013. *Kuwait's Shagaya Project accelerates drive towards PV*. [Online]  
Available at: <http://news.pv-insider.com/photovoltaics/kuwait%E2%80%99s-shagaya-project-accelerates-drive-towards-pv>  
[Accessed 10 June 2014].

Heinberg, R., 2011. *Rising cost of fossil fuels and the coming energy crunch*. [Online]  
Available at: <http://oilprice.com/Energy/Energy-General/Rising-Cost-Of-Fossil-Fuels-And-The-Coming-Energy-Crunch.html>  
[Accessed 27 May 2014].

Hensley, R., Newman, J. & Rogers, M., 2012. *Battery Technology Charges ahead*. [Online]  
Available at:  
[http://www.mckinsey.com/insights/energy\\_resources\\_materials/battery\\_technology\\_charges\\_ahead](http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead)  
[Accessed May 2014].

Hernandez, R. R., 2016. *Land-Energy-Ecology Nexus: Solar energy impacts, nexus issues, and the future solar energy landscape*. [Online]  
Available at:

[http://www.epri.com/Documents/ENV-Vision/EMERGING%20AND%20CROSS-CUTTING%20ISSUES/Environmental%20Impacts%20of%20Renewables/Rebecca%20Hernandez\\_UC%20Davis.pdf](http://www.epri.com/Documents/ENV-Vision/EMERGING%20AND%20CROSS-CUTTING%20ISSUES/Environmental%20Impacts%20of%20Renewables/Rebecca%20Hernandez_UC%20Davis.pdf)  
[Accessed 2017].

- Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Mestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S., Allen, M. F., 2013. *Environmental Impacts of Utility-Scale Solar Energy*, s.l.: El-Sevier: Renewable and Sustainable Energy Reviews.
- Hernandez, R. R., Hoffacker, M. K., Murphy-Mariscal, M. L., Wu, G. C., Allen, M. F., 2015. Solar energy development impacts on land cover change and protected areas. *PNAS*, 112(12), pp. 13579-84.
- Hertog, S., 2009. *Energy and sustainability policies in the GCC*, s.l.: Centre for the Study of Global Governance, London School of Economics and Political Science.
- Hertog, S., 2013. State and private Sector in the GCC after the Arab Uprisings. *Journal of Arabian Studies: Arabia, the Gulf, and the Red Sea*, 3(2), pp. 174-95.
- IEA, 2012. *Tracking clean energy progress*. [Online]  
Available at: [http://www.iea.org/media/etp/Tracking\\_Clean\\_Energy\\_Progress.pdf](http://www.iea.org/media/etp/Tracking_Clean_Energy_Progress.pdf)  
[Accessed 27 May 2014].
- IEA, 2015, *CO2 Emissionss from fuel combustion*. [Online] Available at: <http://www.indiaenvironmentportal.org.in/files/file/CO2EmissionsFromFuelCombustionHighlights2015.pdf>
- IEA, 2016. *CO2 emissions from fuel combustion: Highlights*, Paris, France: OECD/IEA.
- IEA, 2016. *Country Analysis Brief: Kuwait*. [Online]  
Available at: <http://www.dk-export.dk/media/4081575/kuwait-country-analysis-11-16.pdf>
- IEA, 2016. *Oil*. [Online]  
Available at: <http://www.iea.org/about/faqs/oil/>
- IEconomics, 2017. Kuwait inflation rate. [Online]  
Available at: <http://ieconomics.com/kuwait-inflation-rate-forecast>
- Index Mundi, 2017. *Country Comparison: Oil production*. [Online]  
Available at: <http://www.indexmundi.com/g/r.aspx?v=88>  
[Accessed 22 Feb 2017].
- International Energy Agency, 2013. *IEA Statistics; CO2 Emissions from Fuel Combustion*.
- International Energy Agency, 2013. *Key World Energy Statistics*.
- International Energy Agency, 2015. [Online]  
Available at: [http://www.iea.org/stats/electricitydata.asp?COUNTRY\\_CODE=SA](http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=SA)
- International Energy Agency, 2013. *Kuwait: Electricity and Heat 2010*. [Online]  
Available at:  
<http://www.iea.org/statistics/statisticssearch/report/?&country=KUWAIT&year=2010&product=ElectricityandHeat>  
[Accessed November 2013].

International Energy Agency, 2013. *Kuwait: Indicators for 2011*. [Online]  
Available at:  
<http://www.iea.org/statistics/statisticssearch/report/?country=KUWAIT&product=indicators&year=2011>  
[Accessed November 2013].

International Finance Corporation, 2012. *Utility Scale Solar Power Plants*. [Online]  
Available at:  
<http://commdev.org/userfiles/Utility%20Scale%20Solar%20Power%20Plants.pdf>  
[Accessed June 2014].

International Monetary Fund, 2013. *Middle East and Central Asia Department: Kuwait 2013 Article IV Consultation*. [Online]  
Available at: <http://www.cbk.gov.kw/PDF/IMF2013.pdf>  
[Accessed 5 July 2014].

IPCC , 2007. *Climate Change 2007: Synthesis Report*, Geneva, Switzerland: The Intergovernmental Panel on Climate Change [Pachauri, R.K. and A. Reisinger (eds.)].

IPCC, 2014. *Climate Change 2014: Mitigation of Climate Change*, New York, NY: Cambridge University Press.

IPCC, 2014. *Climate Change 2014: Synthesis Report*. [Online]  
Available at: [http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5\\_SYR\\_FINAL\\_All\\_Topics.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf)

IRENA, 2012. *Concentrating Solar Power*. [Online]  
Available at:  
[http://www.irena.org/DocumentDownloads/Publications/RE\\_Technologies\\_Cost\\_Analysis-CSP.pdf](http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf)

IRENA, 2013. *Renewable Energy in the Gulf*. [Online]  
Available at:  
<http://www.irena.org/DocumentDownloads/factsheet/Renewable%20Energy%20in%20the%20Gulf.pdf>

IRENA, 2016a. *Renewable Energy Benefits: Measuring the Economics*, Abu Dhabi: IRENA.

IRENA, 2016b. *Renewable Energy Market Analysis: The GCC Region*. [Online]  
Available at:  
[http://www.irena.org/DocumentDownloads/Publications/IRENA\\_Market\\_GCC\\_2016.pdf](http://www.irena.org/DocumentDownloads/Publications/IRENA_Market_GCC_2016.pdf)

IRENA, 2016. *The Power to Change: Solar and Wind cost Reduction Potential to 2025*. [Online]  
Available at:  
[http://www.irena.org/DocumentDownloads/Publications/IRENA\\_Power\\_to\\_Change\\_2016.pdf](http://www.irena.org/DocumentDownloads/Publications/IRENA_Power_to_Change_2016.pdf)

- Ishii, N., 2012. *Investing in renewable energy: the GEF experience*. [Online]  
Available at:  
[http://d7.thegef.org/sites/default/files/publication/gef\\_renewenergy\\_oct2012\\_r16.pdf](http://d7.thegef.org/sites/default/files/publication/gef_renewenergy_oct2012_r16.pdf)  
[Accessed 27 May 2014].
- Jandal, S., 2014. *A new approach for promoting RE in the Arab Region: The approach for Kuwait*. Tunis, Tunisia, KISR, pp. 4-7.
- Johnstone, N., Hascic, I. & Popp, D., 2008. *Renewable energy policies and technological innovation: Evidence based on patent counts*. [Online]  
Available at: <http://hassler-j.iies.su.se/courses/climate/johnstoneHasicPopp2008.pdf>  
[Accessed May 2014].
- Jordan, D. C. & Kurtz, S. R., 2012. *Photovoltaic Degradation Rates-An Analytical Review*. [Online]  
Available at: <http://www.nrel.gov/docs/fy12osti/51664.pdf>  
[Accessed 5 July 2014].
- Kannan, N. & Vakeesan, D., 2016. Solar energy for future world: A review. *Renewable and Sustainable Energy Reviews*, Volume 62, pp. 1092-1105.
- Kashani, A & Molaei ,R, 2014. Techno-economical and environmental optimization of natural gas network operation. *Chemical Engineering Research and Design*.
- Kanafani, N., 2015. *MENA Economic Outlook-1Q 2015:Kuwait Outlook*. [Online] Available at:  
[http://betakw.nbk.com/investmentandbrokerage/researchandreports/\\$Document/EconomicReports/en-gb/MainCopy/\\$UserFiles/NBK\\_MENA\\_Outlook\\_2015\\_1Q.pdf](http://betakw.nbk.com/investmentandbrokerage/researchandreports/$Document/EconomicReports/en-gb/MainCopy/$UserFiles/NBK_MENA_Outlook_2015_1Q.pdf)
- Karl, T. R., Melillo, J. M. & Peterson, T. C., 2009. *GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES*, New York, NY, USA: United States Global Change Research Program. Cambridge University Press..
- Kearney, A. T.; Hauff, J.; Verdonck, M; Derveaux, H; Dumarest, L; Alberich, J.; Malherbe, J, 2010. *Unlocking the SunBelt: Potential of Photovoltaics*, Brussels, Belgium: EPia.
- Khalid, A. & Junaidi, H., 2012. *Study of economic viability of photovoltaic electric power for Quetta - Pakistan*, Karachi, Pakistan: Elsevier - Renewable Energy.
- Khamis, May; Rodriquez, Pedro; Prasad, Ananthakrishnan; Sensenbrenner, Gabriel; Charap, Joshua; Katayama, Kentaro; Silva, Arthur Da, 2012. *International Monetary Fund Kuwait: Selected Issues and Statistical Appendix*. [Online]  
Available at: <http://www.imf.org/external/pubs/ft/scr/2012/cr12151.pdf>  
[Accessed Aug 2014].



Khoo, H. H. & Tan, R. B., 2006. *Environmental impact evaluation of conventional fossil fuel production (oil and natural gas) and enhanced resources recovery with potential CO<sub>2</sub> sequestration*. [Online]

Available at: <http://pubs.acs.org/doi/abs/10.1021/ef060075%2B>

[Accessed 6 July 2014].

Ki-Moon, B., 2016. Foreword from Ban Ki-Moon. In: *Global Trends in RE Investment 2016*. Frankfurt, Germany: Frankfurt School of Finance & Management, p. 5.

KISR, 2016. *Shagaya Initiative Project 2010-2030: Kuwait Energy Security Vision 2030-Kuwait's Gateway to Future Energy Security*. [Online]

Available at: <http://www.menarec.org/resources/Shagaya+Initiative+progress.pdf>

Klise, Geoffrey T., Tidwell, Vincent, Reno, Marrisa, Moreland, Barbara d., Zemlick, Katie M., Macknick, Jordan, 2013. *Water use and supply concerns for utility-scale solar projects in the Southwestern United States*. [Online]

Available at: [http://energy.sandia.gov/wp/wp-content/gallery/uploads/SAND2013\\_5238.pdf](http://energy.sandia.gov/wp/wp-content/gallery/uploads/SAND2013_5238.pdf)

[Accessed June 2014].

Kossoy, A. & Guigon, P., 2012. *State and Trends of the Carbon Market 2012*. [Online]

Available at: <https://openknowledge.worldbank.org/handle/10986/13335>

[Accessed 5 June 2014].

Kost, Christoph, Mayer, J, Thomsen, J, Hartmann, N, Senkpiel, C, Philipps, S, Nold, S, Lude, S, Saad, N, Schlegel, T, 2013. *Levelized Cost of Electricity Renewable Energy Technologies*. [Online]

Available at: <http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf>

[Accessed 10 June 2014].

Kraus, R. S., 2011. *Exploration, Drilling and Production of Oil and Natural Gas*. [Online]

Available at:

<http://www.ilo.org/oshenc/part-xi/oil-exploration-and-distribution/item/611-exploration-drilling-and-production-of-oil-and-natural-gas>

[Accessed 4 June 2014].

Krupnick, A., Campbell, S., Cohen, M. A. & Parry, I. W., 2011. *Understanding the Costs and Benefits of Deepwater Oil Drilling Regulation*. [Online]

Available at: <http://www.rff.org/documents/RFF-DP-10-62.pdf>

[Accessed July 2014].

Larkin, S., Rajitua, K., Raw, B. & Sheridan, N., 2011. *Pre-feasibility study into solar energy rollout to Namibia: Stakeholder discussion document*. [Online]

Available at:

<http://www.africaninnovation.org/downloads/Namibia%20Electricity%20Strategy.pdf>

[Accessed 10 June 2014].

- Larsen, K., 2009. *End-of-life PV: then what?- Recycling solar PV panels*. [Online]  
Available at: <http://www.renewableenergyfocus.com/view/3005/end-of-life-pv-then-what-recycling-solar-pv-panels/>  
[Accessed 8 June 2014].
- Lazard, 2015. *Lazard's levelized cost of energy analysis-Version 9.0*. [Online]  
Available at: <https://www.lazard.com/media/2390/lazards-levelized-cost-of-energy-analysis-90.pdf>
- Ledley, T.S., Sundquist, E.T., Schwartz, S. E., Hall, D, Fellows, D. J., Killen, T. L., 1999. Climate Change and Greenhous Gases. *EOS*, 80(39), pp. 453-74.
- Lee, A., Zinaman, O. & Logan, J., 2012. *Opportunities for synergy between natural gas and renewable energy in the electtric poweer and transportaion sectors*. [Online]  
Available at: <http://www.nrel.gov/docs/fy13osti/56324.pdf>  
[Accessed 2 June 2014].
- Lee, S., Speight, J. G. & Loyalk, S. K., 2007. *Handbook of alternative fuel technologies: Green chemistry and chemical engineering*. Boca Raton, Florida: CRC Press.
- Logan, Jeffrey, Heath, Garvin, Macknick, Jordan, Paranhos, Elizabeth; Boyd, William; Calson, Ken, 2012. *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity*. [Online]  
Available at: <http://www.nrel.gov/docs/fy13osti/55538.pdf>  
[Accessed 6 June 2014].
- Lovich, J. & Ennen, J. R., 2011. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. *BioScience*, Volume 61, pp. 982-92.
- Mani, M. & Pillai, R., 2010. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renewable and Sustainable Energy Reviews*, 14(1), pp. 3124-31.
- Marchal, Virginie, Dellink, Rob, Vuuren, Detlef van, Clapp, Christa, Chateau, Jean, Lanzi, Eliza, Magne, Bertrand, Vliet, Jasper van, 2011. *OECD Environmental Outlook to 2050: Climate Change Chapter*. [Online]  
Available at: <http://www.oecd.org/env/cc/49082173.pdf>  
[Accessed July 2014].
- Mariasiu, F., 2012. Energy sources management and future automotive technologies: Environmental impact. *International Journal of Energy Economics and Policy*, 2(4), pp. 342-47.
- Mason, M. & Mor, A., 2009. *Renewable energy in the Middle East enhancing security through regional cooperation..* [Online]  
Available at: <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=478126>

Mehta, P., 2015. A conceptual understanding of scientific and legal perspective of acid precipitation and its impacts: A review. *Journal of Applied Science and Research*, 3(2), pp. 54-75.

MENA, 2013. *Renwables Status Report*. [Online]

Available at:

[http://www.ren21.net/Portals/0/documents/activities/Regional%20Reports/MENA\\_2013\\_lowres.pdf](http://www.ren21.net/Portals/0/documents/activities/Regional%20Reports/MENA_2013_lowres.pdf)

[Accessed Aug 2014].

MENA-OECD, 2011. *Assessing investment policies of member countries of the Gulf Cooperation Council*. [Online]

Available at:

<http://www.oecd.org/mena/investment/Preliminary%20assessment%20GCC%20inv%20policies.pdf>

[Accessed Aug 2014].

MEW, 2014. *Energy Conservation Program: Code of Practice*. [Online]

Available at: <http://www.mew.gov.kw/media/The%20Code%20-%20Master%20copy.pdf>

MEW, 2016. *State of Kuwait: Statistical Year Book*. [Online]

Available at: <http://www.mew.gov.kw/media/Statistics/Electricity%20Book.pdf>

Ming, T., Richter, R. L. W. & Caillol, S., 2014. Fighting global warming by climate engineering: Is the Earth radiation management and the solar radiation management any option for fighting climate change?. *Renewable and Sustainable Energy Reviews*, Volume 31, pp. 792-834.

Ministry of Electricity and Water - Kuwait, 2009. *2009 Electricity Statistics - Chapter 02: Electric Energy*. [Online]

Available at: <http://www.mew.gov.kw/?com=content&id=243&act=view>

[Accessed November 2013].

Ministry of Electricity and Water - Kuwait, 2009. *2009 Electricity Statistics - Chapter 07: Fuel Networks*. [Online]

Available at: <http://www.mew.gov.kw/?com=content&id=243&act=view>

[Accessed November 2013].

Ministry of Electricity and Water - Kuwait, 2013. *Historical Glimpses About Electricity Generation in Kuwait [Translated from Arabic]*. [Online]

Available at: <http://www.mew.gov.kw/?act=view&com=content&id=73>

[Accessed November 2013].

Mohamed A., Hasan, A. 2012. Effect of Dust Accumulation on Performance of Photovoltaic Solar Modules in Sahara Environment. *Journal of Basic and Applied Scientific Research*.

Available at: [http://](http://rollingwash.net/docs/Effect%20of%20Dust%20Accumulation%20on%20PV%20Solar%20Modules%20in%20Sahara%20Environment.pdf)

[rollingwash.net/docs/Effect%20of%20Dust%20Accumulation%20on%20PV%20Solar%20Modules%20in%20Sahara%20Environment.pdf](http://rollingwash.net/docs/Effect%20of%20Dust%20Accumulation%20on%20PV%20Solar%20Modules%20in%20Sahara%20Environment.pdf)

- Moss, J., Coram, A. & Blashki, G., 2014. *Solar Energy in Australia: Health and Environmental Cost and Benefits*. [Online]  
Available at:  
[http://www.tai.org.au/sites/default/files/WEB%20Solar%20energy%20in%20Australia\\_1.pdf](http://www.tai.org.au/sites/default/files/WEB%20Solar%20energy%20in%20Australia_1.pdf)
- NASA, 2013. *Global Climate Change*. [Online]  
Available at:  
[http://climate.nasa.gov/state\\_of\\_flux?CFID=1655704&CFTOKEN=79076233#Globalwarming.jpg](http://climate.nasa.gov/state_of_flux?CFID=1655704&CFTOKEN=79076233#Globalwarming.jpg)  
[Accessed November 2013].
- National Climatic Data Center, 2013. *Greenhouse Gases*, s.l.: National Oceanic and Atmospheric Administration (NOAA).
- Naufal, G. & Genc, I., 2014. Labor Migration in the GCC Countries: past, present and future. *SMEP*, 9(2), pp. 1-28.
- Nduka, J. K., Okafor, V. N. & Odiba, I. O., 2016. Impact of oil and gas activities on acidity of rain and surface water of Niger Delta, Nigeria: An environmental and public health review. *Journal of Environmental Protection*, Volume 7, pp. 566-581.
- Ngo, C. & Natowitz, J., 2012. *Our Energy Future: Resources, Alternatives and Environment*. 16 ed. Hoboken, NJ: John Wiley & Sons.
- Nicoletti, G., Arcuri, N., Nicoletti, G. & Bruno, R., 2015. A technical and environmental comparison between hydrogen and some fossil fuels. *Energy Conversion and Management*, Volume 89, pp. 205-13.
- Niel, S, Beattie, R, Moir, Charleslee, Chacko, Giorgio B, Roberts, S, Pearsalla, N, 2012. Understanding the effects of sand and dust accumulation on photovoltaic modules. *Renewable Energy*, 48(1), pp. 448-452.
- NOAA, 2010. *Oil Spills and Coral Reefs*. [Online]  
Available at: [http://www.noaa.gov/factsheets/new%20version/coralreefs\\_oil.pdf](http://www.noaa.gov/factsheets/new%20version/coralreefs_oil.pdf)  
[Accessed 2014].
- Nordell, B., 2003. Thermal pollution causes global warming. *Global and Planetary Change*, 27 Jan, 38(1), pp. 305-12.
- NRG Magazine, 2014. *International cooperation in energy and energy law: Sustainability's toolkit*. [Online]  
Available at: <http://www.nrgmagazine.nl/articles/energy/articles/international-cooperation-energy-and-energy-law-sustainabilitys-toolkit/>  
[Accessed May 2014].
- Nrcan, 2017. Canada.Online  
Available at: <http://www.nrcan.gc.ca/energy/software-tools/7465>

- Oil-Price.net, 2017. *Crude Oil and Commodity Prices*. [Online]  
Available at: <http://www.oil-price.net/>  
[Accessed 24 Feb 2017].
- Olivier, J. G., Green, J., Muntean, M. & Peters, J. A., 2015. *Trends in global CO2 emissions: 2015 report*, The Hague: PBL Netherlands Environmental Assessment Agency.
- Olivier, J. G., Green, J., Muntean, M. & Peters, J. A., 2016. *Trends in global CO2 emissions: 2016 Report*, The Hague: PBL Netherlands Environmental Assessment Agency.
- Ombugus, W. M., 2016. Acid rain a menace to construction industry. *International Journal of Scientific Engineering and Applied Science (IJSEAS)*, 2(1), pp. 268-78.
- OPEC, 2016. *OPEC Annual Statistical Bulletin*. [Online]  
Available at:  
[http://www.opec.org/opec\\_web/static\\_files\\_project/media/downloads/publications/ASB2016.pdf](http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2016.pdf)
- Owens, G., 2002. *Economic & Financial evaluation of renewable energy projects*. [Online]  
Available at: [http://pdf.usaid.gov/pdf\\_docs/PNADB613.pdf](http://pdf.usaid.gov/pdf_docs/PNADB613.pdf)  
[Accessed 27 May 2014].
- Oyedepo, S. O., 2012. *Energy and sustainable development in Nigeria: the way forward*. [Online]  
Available at: <http://www.energysustainsoc.com/content/2/1/15>  
[Accessed 27 May 2014].
- PB, 2013. *BP Statistical Review of World Energy June 2013*. s.l.:s.n.
- PE-international (2012). [Online]  
Available at: <http://www.gabi-software.com>.  
[Accessed 8 OCT 2017].
- Phinikarides, A., Kindyni, N., Makrides, G. & Georghiou, G. E., 2014. Review of photovoltaic degradation rate methodologies. *Renewable and Sustainable Energy Reviews*, Volume 40, pp. 143-152.
- Pichtel, J., 2016. Oil and Gas Production: Soil contamination and Pollution Prevention. *Applied and Environmental Soil Science*, Issue doi:10.1155/2016/2707989, pp. 1-24.
- Pickrell, K., DeBenedictis, A., Mahone, A. & Price, S., 2013. *Cost-Effectiveness of rooftop photovoltaic systems for considration in California's building energy efficiency standards*. [Online]  
Available at: <http://www.energy.ca.gov/2013publications/CEC-400-2013-005/CEC-400-2013-005-D.pdf>  
[Accessed 13 June 2014].
- Ports.com. (2017). *World seaports catalogue, marine and seaports marketplace*. [online]  
Available at: <http://ports.com> [Accessed Oct. 2017].

Population Reference Bureau, 2016. *2016 World Population Data Sheet: A Special Focus on Human Needs and Sustainable Resources*. [Online]  
Available at: <http://www.prb.org/pdf16/prb-wpds2016-web-2016.pdf>

PRé, 2016. SimaPro Database Manual. [Online]  
Available at: <https://www.pre-sustainability.com/download/DatabaseManualMethods.pdf>

Preston, M., 2011. *Renewable energy in Qatar*. [Online]  
Available at: <http://www.nortonrosefulbright.com/knowledge/publications/48660/renewable-energy-in-qatar>

Preston, M., 2012. *Renewable energy in Saudi Arabia*. [Online]  
Available at: <http://www.nortonrosefulbright.com/knowledge/publications/61454/renewable-energy-in-saudi-arabia>  
[Accessed Aug 2013].

Prockop, L. D. & Chichkova, R. I., 2007. Carbon monoxide intoxication: An updated review. *Journal of the Neurological Science*, 262(1), pp. 122-30.

PWC, 2013. *Shale oil: the next energy revolution*. [Online]  
Available at: [http://www.pwc.se/sv\\_SE/se/energi/assets/shale-oil-the-next-energy-revolution.pdf](http://www.pwc.se/sv_SE/se/energi/assets/shale-oil-the-next-energy-revolution.pdf)  
[Accessed 4 JUNE 2014].

Rajput, D. S. & Sudhakar, K., 2013. Effect of Dust on the Performance of Solar PV Panel. *International Journal of Chem Tech Research*, 5(2), pp. 1083-86.

Ramadhan, M. & Hussain, A., 2012. Kuwait energy profile for electrical power generation. *Journal of Strategic Planning for Energy and the Environment*, 32(1), pp. 18-25.

Ramadhan, M., Hussain, A. & Behbehani, D., 2012. *The prospect of solar energy in the development of power station in the State of Kuwait*. [Online]  
Available at: <http://www.hindawi.com/journals/jre/2013/374265/>  
[Accessed 5 July 2014].

Ramadhan, M., Hussain, A. & Behbehani, D., 2012. *The prospect of Solar Energy in the Development of Power Stations in the State of Kuwait*. [Online]  
Available at: <http://www.hindawi.com/journals/jre/2013/374265/>  
[Accessed 10 June 2014].

Ramadhan, M. & Naseeb, A., 2010. *The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait*, Kuwait, Kuwait: Elsevier - Renewable Energy.

Ramadhan, M. & Naseeb, A., 2011. The Cost Benefit Analysis of Implementing Photovoltaic Solar System-1276 in the State of Kuwait. *Renewable Energy*, 36(4), p. 1272.

Ramady, M. A., 2012. *The GCC economies stepping up to future challenges*, New York: Springer Science+Business Media..

Raugei, M. & Frankl, P., 2009. *Life cycle impacts and costs of photovoltaic systems: Current state of the art and future outlooks*, Barcelona, Spain: Elsevier - Energy.

Reiche, D., 2009. *Renewable Energy Policies in the Gulf countries: A case study of the carbon-neutral "Masdar City" in Abu Dhabi*, Beirut, Lebanon: Elsevier - Energy Policy.

Reiche, D., 2010. Energy Policies of Gulf Cooperation Council countries-possibilities and limitation of ecological modernization in rentier states. *Energy Policy*, 38(5), pp. 2395-2403.

Said, M.; El-Shimy, M.; Abdelraheem, M.A., 2015. *Photovoltaics energy: Improved modeling and analysis of the levelized cost of energy (LCOE) and grid parity - Egypt case study. Sustainable Energy Technologies and Assessments*.

Sawin, J. L., 2013. *Renewables 2013: Global status report*. [Online]

Available at:

[http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013\\_lowres.pdf](http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013_lowres.pdf)

[Accessed 27 May 2014].

Schmidt, R. C. & Marschniski, R., 2009. A model of technological breakthrough in the renewable energy sector. *Ecological Economics*, 69(2), pp. 435-44.

Science for Environmental Policy, 2010. *Air Quality and Atmospheric Pollution in the Arab region*. [Online]

Available at: <http://ec.europa.eu/environment/integration/research/newsalert/pdf/24si.pdf>

[Accessed 10 June 2014].

ScienceDaily, 2008. *Impacts of Fossil Fuels on Fish and People*. [Online]

Available at: <http://www.energymanagertraining.com/Journal/Best%20Practice%20Brochure-004-Feb-02.pdf>

[Accessed 5 June 2014].

Seel, J., Barbose, G. L. & Wiser, R. H., 2014. *An analysis of residential PV system price differences between the United States and Germany*. [Online]

Available at: [https://emp.lbl.gov/sites/all/files/lbnl-6614e\\_0.pdf](https://emp.lbl.gov/sites/all/files/lbnl-6614e_0.pdf)

Shimy, M. E. -, 2009. *Viability analysis of PV power plants in Egypt*, Cairo, Egypt: Elsevier - Renewable Energy.

Sims, Ralph, Schock, Robert, Adegbululgbé, Anthony, Asmussen, Arne, Golay, Michael, 2007. *Energy Supply*. [Online]

Available at: <https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf>

[Accessed 4 June 2014].

Social.csptoday.com, 2013. *Kuwait's solar journey comes to light | CSP Today*. [Online]

Available at: <http://social.csptoday.com/markets/kuwait%E2%80%99s-solar-journey-comes-light>

[Accessed 19 September 2013].

- Solar GCC Alliance, 2014. *Solar Update*. [Online]  
Available at: <http://www.solargcc.com/kuwait-solar/>  
[Accessed 5 July 2014].
- Speight, J. & Exall, D., 2014. *Refining used lubricating oils*. Boca Raton, FL: Taylor & Francis Group, LLC.
- Speight, J. G., 2013. *Coal-Fired Power Generation Handbook*. Beverly, MA: Scrivener Publishing.
- Steinberg, M., 1995. *Decarbonization and Sequestration for Mitigating Global Warming*. Upton; NY: Brookhaven National Laboratory.
- Stiftung, B., 2014. *BTI- Kuwait Country Report*. [Online]  
Available at: [https://www.bti-project.org/fileadmin/files/BTI/Downloads/Reports/2014/pdf/BTI\\_2014\\_Kuwait.pdf](https://www.bti-project.org/fileadmin/files/BTI/Downloads/Reports/2014/pdf/BTI_2014_Kuwait.pdf)
- Stoms, D. M., Dashiell, S. L. & Davis, F. W., 2013. Siting solar energy development to minimize biological impacts. *Renewable Energy*, Volume 57, pp. 289-298.
- Sweet, C., 2014. *The \$2.2 Billion Bird-scorching Solar Project*. [Online]  
Available at:  
<http://online.wsj.com/news/articles/SB10001424052702304703804579379230641329484>  
[Accessed 8 June 2014].
- Swift, K. D., 2013. *A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations accross the United States*, Missoula, MT: Elsevier - Renewable Energy.
- Taleb, H. & Pitts, A., 2009. The potential to exploit use of building-integrated photovoltaics in countries of the Gulf Cooperation Council. *Renewable Energy*, Issue 34, pp. 1092-1099.
- Taylor, P., d'Ortigue, O. L., Trudeau, N. & Francoeur, M., 2008. *Energy efficiency indicators for public electricity production from fossil fuels*. [Online]  
Available at:  
[http://www.iea.org/publications/freepublications/publication/En\\_Efficiency\\_Indicators.pdf](http://www.iea.org/publications/freepublications/publication/En_Efficiency_Indicators.pdf)  
[Accessed 4 June 2014].
- The American Petroleum Institute, 2013. *Facts about Fossil Fuels*, s.l.
- The State of Kuwait, 2015. *Intended Nationally Determined Contributions*. [Online]  
Available at:  
[http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Kuwait/1/Kuwait\\_IND\\_Cs\\_English\\_Version.pdf](http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Kuwait/1/Kuwait_IND_Cs_English_Version.pdf)
- The World Factbook, 2014. *Kuwait*. [Online]  
Available at: <https://www.cia.gov/library/publications/the-world-factbook/geos/ku.html>  
[Accessed 5 July 2014].



Thomson Reuters, 2016. *Carbon Market Monitor-America to the rescue: Review of global markets in 2015 and outlook for 2016-2018*. [Online]

Available at: <https://climateobserver.org/wp-content/uploads/2016/01/Carbon-Market-Review-2016.pdf>

[Accessed 2017].

Tsoutsos, T., Frantzeskaki, N. & Gekas, V., 2005. Environmental impacts from the solar energy technologies. *Energy Policy*, 33(1), pp. 289-96.

Turney, D. & Fthenakis, V., 2011. *Environmental impacts from the installation and operation of large-scale solar power plants*, New York: ELSEVIER - Renewable and Sustainable Energy Reviews.

Turney, D. & Fthenakis, V., 2011. Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, 15(1), pp. 3261-70.

UCS, 2013. *The Hidden cost of Fossil fuels*. [Online]

Available at: [http://www.ucsusa.org/clean\\_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html](http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html)

[Accessed 4 June 2014].

Ulrichsen, K. C., 2016. *The Politics of Economic Reform In Arab Gulf States*. [Online]

Available at: <http://www.bakerinstitute.org/media/files/files/717a5914/CME-GulfEconReform-060116.pdf>

UN\_FCCC, 2015. *Conference of the Parties: Adoption of the Paris Agreement*. Paris, France, Framework Convention on Climate Change.

UNEP, 2007. *Current status of Renewable Energies in the Middle East-North African region*. [Online]

Available at: [http://www.unep.org/pdf/rowa/Renewable\\_Energy.pdf](http://www.unep.org/pdf/rowa/Renewable_Energy.pdf)

[Accessed 5 July 2014].

UNFCCC, 2016. *COP 22*. [Online]

Available at: [http://unfccc.int/meetings/marrakech\\_nov\\_2016/session/9676.php](http://unfccc.int/meetings/marrakech_nov_2016/session/9676.php)

Union of Concerned Scientists, 2013. *The Hidden Cost of Fossil Fuels*. [Online]

Available at:

[http://www.ucsusa.org/clean\\_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html](http://www.ucsusa.org/clean_energy/our-energy-choices/coal-and-other-fossil-fuels/the-hidden-cost-of-fossil.html)

[Accessed November 2013].

United Nations Framework Convention on Climate Change, 2013. *Kuwait Emissions Summary*. [Online]  
Available at:  
[http://unfccc.int/files/ghg\\_data/ghg\\_data\\_unfccc/ghg\\_profiles/application/pdf/kwt\\_ghg\\_profile.pdf](http://unfccc.int/files/ghg_data/ghg_data_unfccc/ghg_profiles/application/pdf/kwt_ghg_profile.pdf)  
[Accessed November 2013].

United Nations, 2012. *Kyoto Protocol*. [Online]  
Available at: [http://unfccc.int/kyoto\\_protocol/items/2830.php](http://unfccc.int/kyoto_protocol/items/2830.php)  
[Accessed 7 June 2014].

United Nations, 2016. *United Nations Paris Climate Agreement Signing Ceremony: List of Parties that signed the Paris Agreement on 22 April*. [Online]  
Available at:  
<http://www.un.org/sustainabledevelopment/blog/2016/04/parisagreementsignatures/>  
[Accessed 26 Sep 2016].

United States Environmental Protection Agency, 2013. *Greenhouse Gas Emissions*. [Online]  
Available at: <http://www.epa.gov/climatechange/ghgemissions/>  
[Accessed November 2013].

Upton, H. F., 2011. *The Deepwater Horizon Oil Spill and the Gulf of Mexico Fishing Industry*. [Online]  
Available at: <http://fas.org/sgp/crs/misc/R41640.pdf>  
[Accessed 17 Aug. 2014].

Varun, Parkash, R. & Bhat, I. K., 2009. *Energy, Economics, and Environmental impacts of renewable energy systems*, s.l.: ELSEVIER - Renewable and Sustainable Energy Reviews.

Velyvis, S. E., Burke & Sorensen, W., 2015. *AB 2188 Implementation Requirements for Rooftop Solar Systems*. [Online]  
Available at: <https://www.cacities.org/Resources-Documents/Member-Engagement/Professional-Departments/City-Attorneys/Library/2015/2015-Spring-Conference/5-2015-Spring-Stephen-Velyvis-AB-2188-Implementati.aspx>

Venture Onsite, 2016. *GCC Power Market Overview- 2016*. [Online]  
Available at: <http://www.transformers-magazine.com/images/News/PDF/GCC-Power-Market-2016.pdf>

VGB PowerTech, 2015. *Levelised cost of electricity (LCOE)*, Essen, Germany: VGB PowerTech e.V..

Weiss, J., Bishop, H., Fox-Penner, P. & Shavel, I., 2013. *Partnering Natural Gas and Renewables in ERCOT*. [Online]  
Available at: <http://www.texascleanenergy.org/Brattle%20report%20on%20renewable-gas%20FINAL%2011%20June%202013.pdf>  
[Accessed June 2014].

- Whitburn, G., 2011. *Solar Panels*. [Online]  
Available at: <http://exploringgreentechnology.com/solar-energy/cost-of-solar-panels/>  
[Accessed 10 June 2014].
- World Energy Council, 2013. *World Energy Sources: 2013 Survey*. [Online]  
Available at: [http://www.worldenergy.org/wp-content/uploads/2013/09/Complete\\_WER\\_2013\\_Survey.pdf](http://www.worldenergy.org/wp-content/uploads/2013/09/Complete_WER_2013_Survey.pdf)  
[Accessed June 2014].
- World Bank, Ecofys & Vivid Economics, 2016. *State and Trends of Carbon Pricing 2016*, Washington DC: International Bank for Reconstruction and Development/ The World Bank.
- World Energy Council, 2016. *World Energy Resources Full Report 2016*. [Online]  
Available at: <https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf>
- World Nuclear Association, 2012. *Uranium, Electricity and Climate Change*. [Online]  
Available at: <http://www.world-nuclear.org/info/Energy-and-Environment/Uranium,-Electricity-and-Climate-Change/>  
[Accessed 12 Aug 2014].
- World Nuclear Association, 2013. *Climate change-The Science*. [Online]  
Available at: <http://www.world-nuclear.org/info/energy-and-environment/climate-change---the-science/>  
[Accessed 6 June 2014].
- Yessian, K., DeLaquil, P., Merven, B. & Corporation, L., 2013. *Economic Analysis of Clean Energy Options for Kuwait*. [Online]  
Available at: [http://www.decisionwaregroup.com/assets/kuwait\\_economic-analysis-of-nuclear-and-renewable-energy-options.pdf](http://www.decisionwaregroup.com/assets/kuwait_economic-analysis-of-nuclear-and-renewable-energy-options.pdf)  
[Accessed 5 July 2014].
- Yessian, K., Delaquil, P., Merven, B., Garguilo, M., Goldstein, G., 2013. Economic analysis of clean energy options for Kuwait.. *International Journal of Energy Sector Management*, Issue 7, pp. 29-45.
- Yu, C.-H., Huang, C.-H. & Tan, C.-S., 2012. A Review of CO<sub>2</sub> Capture by Absorption and Adsorption. *Aerosol and Air Quality Research*, 12(1), pp. 745-69.
- Zielnik, A. F. & Dumbleton, D. P., 2012. *Will your module last outdoors*. [Online]  
Available at: [http://atlas-mts.com/fileadmin/downloads/Atlas25\\_whitepaper.pdf](http://atlas-mts.com/fileadmin/downloads/Atlas25_whitepaper.pdf)  
[Accessed 30 June 2014].

## **APPENDIX: A**

### **INTERVIEWS**

Although the literature has given a review of the current state, the author, works in the Ministry of Electricity in Kuwait, and through connections within the Ministry of Electricity was aware there is a future project planned aimed at adopting PV, solar thermal and wind. One such project is the “Alshagaya” project.

It is anticipated that the outcome of the Alshagaya project will have an influence on the future activities within Kuwait. To obtain insight into the plans, the author approached both the Ministry of Electricity and Kuwait Institution for Scientific Research to discuss the proposed project.

As all the project details are not in the public domain the researcher arranged meetings to discuss project Alshagaya and future plans for Kuwait to identify the future needs/expectations from the ministries in Kuwait. The approach adopted to gather the information was through undertaking semi-structured interviews to allow the interviewees the freedom to express their own views as they see in their own terms. The key information the author wished to identify was:

- What is the future plans for Kuwait?
- Explanation of the “Alshagaya” project (not in public domain)
- The interviewee’s personal viewpoint on the adoption of RET.
- Ascertain what the government may require from the research being undertaken by the author.

Two people were interviewed Mr Abdal from the Ministry of Electricity (MEW) and Dr Alqattan from the Kuwait Institute for Scientific Research (KISR).

### **Ministry of Electricity and Water**

**Interviewee:** Mr. Nabeel Abdal

**Interests:** Renewable projects in Kuwait.

**Job:** Manager for future plans in Ministry of Electricity and Water (MEW).

### **Future plans for Kuwait and why**

Mr Nabeel confirms that the need of electricity in Kuwait is increasing rapidly and in these years the amount of consumption, in summer, the peak load is almost equal to the maximum capacity of the current power stations which may leads to power-blackouts which put Kuwait in need to build new power stations.

### **The “Alshagaya” project**

Ministry of Electricity will connect “Alshagaya” project Phase1 to the national electricity grid as soon as it finish by building substation and overhead lines. Tenders are now open to build the substation and overhead lines.

### **Interviewee personal viewpoint on the adoption of RET and his opinion on the research being undertaken by the author.**

Mr Nabeel is looking forward to see phase1 (70MW) is connected to the electricity grid as it is the starting part of the 2000 MW plan (2030) and confirms that there is a lack of studies on RET in Kuwait, such a research may give clearer view and help in reducing decision making time in the Ministry.

### **Kuwait Institute for Scientific Research (KISR)**

**Interviewee:** Dr. Ayman Alqattan

**Interests:** Renewable projects in Kuwait.

**Job:** Manager of Renewable Energy Program at Kuwait Institute for Scientific Research (KISR).

### **The “Alshagaya” project**

The “ Alshagaya “ project that it consist of three phases, currently starting on phase1 consisting of 50 MW of solar thermal, 10 megawatt solar photovoltaic and 10 megawatt wind plants (70MW in total) will form together the initial stage of deploying 2,000 megawatt by 2030. At the end of phase1 it is estimated that this will prevent 200,000 ton of CO<sub>2</sub> emission per year. Phase1 will serve 5000 households per year. Table 3 shows a brief of Alshagaya project plan.

Dr. Alqattan illustrates that the main aims of phase1, after energy production, KISR will have clearer and more accurate number of the cost of kWh of electricity produced by RE in Kuwait, which will help and used in the future tenders to cover the 2000 Megawatt (2030 plan), Table 3 shows the project plan.

### **Interviewee personal viewpoint on the adoption of RET and his opinion on the research being undertaken by the author.**

Dr Ayman is motivated on the project since it is the first large scale RE project to be applied in Kuwait. He agrees that the research being taken by the author may be beneficial for Kuwait since it starts to take into consideration the renewable energy sources available.

### **Findings**

Both interviewees agreed that there is a lack of studies on the environmental impact of renewable energy in Kuwait, the same as the accurate price of kWh of electricity from RET. From the literature it can be initially concluded that the implementation of PV power stations is economically viable and favorable and it is environmentally convenient and beneficial to adopt large-scale power stations based on Solar Photovoltaic technology in Kuwait. However, it is still not clear what is the whole cost of the kWh of electricity produced from RE in Kuwait. The main aim of the phase1 of Alshagaya project is to have a good estimation for the

value of the kWh and observe the initial environmental impact. In the same time there are still no current studies on the environmental impact of such large-scale stations in Kuwait. Where both interviewees agreed and looking forward to more studies and projects, in Kuwait, in this field.

